Heavy Vector and Axial-Vector Mesons in Asymmetric Strange Hadronic Matter

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Abstract

We calculate the effects of finite density of isospin asymmetric strange hadronic matter, for different strangeness fractions, on the in-medium properties of vector (D^*, D_s^*, B^*, B_s^*) and axial-vector $(D_1, D_{1s}, B_1, B_{1s})$ mesons using chiral hadronic SU(3) model and QCD sum rules. We focus on the evaluation of in-medium mass-shift and shift of decay constant of above vector and axial vector mesons. In QCD sum rule approach the properties e.g. masses and decay constants of vector and axial vector mesons are written in terms of quark and gluon condensates. These quarks and gluon condensates are evaluated in the present work using chiral SU(3) model through the medium modification of scalar-isoscalar fields σ and ζ, the scalar-isovector field δ and scalar dilaton field χ in strange hadronic medium which includes both nucleons as well as hyperons. As we shall see in detail the masses and decay constants of heavy vector and axial vector mesons are affected significantly due to isospin asymmetry and strangeness fraction of the medium and these modifications may influence the experimental observables produced in heavy ion collision experiments. The results of present investigations of in-medium properties of vector and axial-vector mesons at finite density of strange hadronic medium may be helpful for understanding the experimental data from heavy-ion collision experiments in-particular for the Compressed Baryonic Matter (CBM) experiment of FAIR facility at GSI, Germany.

Keywords: Dense hadronic matter, strangeness fraction, heavy-ion collisions, effective chiral model, QCD sum rules, heavy mesons.

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I. INTRODUCTION

The aim of relativistic heavy-ion collision experiments is to explore the different phases of QCD phase diagram so as to understand the underlying strong interaction physics of Quantum Chromodynamics. The different regions of QCD phase diagram can be explored by varying the beam energy in the high energy heavy-ion collision experiments. The nucleus-nucleus collisions at the Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) experiments explore the region of the QCD phase diagram at low baryonic densities and high temperatures. However, the objective of the Compressed Baryonic Matter (CBM) experiment of FAIR project at GSI, Germany is complementary to RHIC and LHC experiments. It aims to study the region of phase diagram at high baryonic density and moderate temperature. In nature these kind of phases may exist in astrophysical compact objects e.g. in neutron stars. Among the many different observable which may be produced in CBM experiment the one of them may be the production of mesons having charm quark or antiquark. Experimentally, charm meson spectroscopy as well as their in-medium properties are also of interest from the point of view of PANDA experiment of FAIR project where $\bar{p}A$ collisions will be performed. The possibility of production of open or hidden charm mesons motivate the theoretical physicist to study the properties of these mesons in dense nuclear matter. The discovery of many open or hidden charm or bottom mesons at CLEO, Belle or BABAR experiments [1–3] attract the attentions of theoretical groups to study the properties of these mesons.

Quark meson coupling model [4], coupled channel approach [5–7], QCD sum rules [8–11] or chiral hadronic models [12–16] etc are among the many theoretical approaches used for investigating the in-medium properties of hadrons. The theoretical investigations of open or hidden charmed meson properties at finite density or temperature of the nuclear matter may help us in understanding their production rates, decay constants, decay widths etc in heavy-ion collision experiments. The study of open charm D mesons also help in understanding the phenomenon of J/ψ suppression produced in heavy-ion collisions. The higher charmonium states are considered as major source of J/ψ mesons. However, if the D mesons undergo mass drop in the nuclear matter and the in-medium mass of $D\bar{D}$ pairs falls below the threshold value of excited charmonium states then these states can also decay to $D\bar{D}$ pairs and may cause a decrease in the yield of J/ψ mesons. In ref. [16] the pseudoscalar D and $\bar{D}$ mesons

were investigated by generalizing the chiral SU(3) model to SU(4) and the in-medium masses were calculated at finite density of nuclear and strange hadronic matter. The masses of D and $\bar{D}$ mesons were found to be sensitive to the density as well as the strangeness fraction of the hadronic medium. The chiral hadronic model is recently also generalized to SU(5) sector so as to investigate the effects of density and strangeness fractions on the in-medium masses of open bottom mesons B, $\bar{B}$ and B_S. In ref.[9] the Borel transformed QCD sum rules were used to study the pseudoscalar D meson mass modifications in the nuclear medium. The mass splitting of D and $\bar{D}$ mesons was investigated using QCD sum rules in [8]. The study of medium modifications of D and $\bar{D}$ mesons may help us in understanding the possibility of formation of charmed mesic nuclei. The charmed mesic nuclei are the bound states of charm mesons and nucleon formed through strong interactions. In ref. [4] the mean field potentials of D and $\bar{D}$ mesons were calculated using the quark meson coupling (QMC) model under local density approximation and the possibilities of the formation of bound states of D^-, D^0 and $\bar{D}^0$ mesons with Pb(208) were examined. The properties of charmed mesons in the nuclei had also been studied using the unitary meson-baryon coupled channel approach and incorporating the heavy-quark spin symmetry [17, 18].

The in-medium mass modifications of scalar, vector and axial vector heavy D and B mesons were investigated using the QCD sum rules in the nuclear matter in [10, 11]. Recently we studied the mass-modifications of scalar, vector and axial vector heavy charmed and bottom mesons at finite density of the nuclear matter using the chiral SU(3) model and QCD sum rules [19]. In this approach we evaluated the medium modifications of quark and gluon condensates in the nuclear matter through the medium modification of scalar isoscalar fields σ and ζ and the scalar dilaton field χ. In the present paper our objective is to work out the in-medium masses and decay constants of heavy charmed vector (D^*, D_s^*) and axial-vector (D_1, D_{1s}) as well as bottom vector (B^*, B_s^*) and axial-vector (B_1, B_{1s}) mesons in the isospin asymmetric strange hadronic medium using the chiral SU(3) model and QCD sum rules. In the QCD sum rules the properties of above mesons are modified through the quark and gluon condensates. Within the chiral hadronic model the quark and gluon condensates are written in terms of scalar fields σ, ζ and δ and the scalar dilaton field χ. We shall evaluate the σ, ζ, δ and χ fields and hence the quark and gluon condensates in the medium consisting of nucleons and hyperons. We shall evaluate the values of quark and gluon condensates as a function of density of strange hadronic medium for different strangeness fractions and shall

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find the mass shift and shift of decay constants of heavy vector and axial vector mesons. The study of decay constant of heavy mesons play important role in understanding the strong decay of heavy mesons, their electromagnetic structure as well radiative decay width. The study of B meson decay constants is important for B_d-$\bar{B}_d$ and B_s-$\bar{B}_s$ mixing [20]. The decay constants of vector D^* and B^* mesons are helpful for calculations of strong coupling in $D^*D\pi$ and $B^*B\pi$ mesons using light cone sum rules [21]. An extensive literature is available on the calculations of decay constants of heavy mesons in the free space, for example, the QCD sum rules based on operator product expansion of two-point correlation function, heavy-quark expansion [22], sum rules in heavy-quark effective theory [23, 24] and sum rules with gluon radiative corrections to the correlation functions upto two loop [25–27] or three loop [28]. However, the in-medium modifications of decay constants of heavy mesons had been studied very recently in symmetric nuclear matter only [29, 30]. The thermal modification of decay constants of heavy vector mesons was investigated in ref. [31] and it was observed that the values of decay constants remained almost constant upto 100 MeV but above this decrease sharply with increase in temperature. In the present work we shall include the contribution of hyperons in addition to nucleons for evaluating the modification of mesons properties in asymmetric matter.

We shall present this work as follows: In section (II) we shall describe the chiral SU(3) model which is used to evaluate the quark and gluon condensates in the strange hadronic matter. Section (III) will introduce the QCD sum rules which we shall use in the present work along with chiral model to evaluate the in-medium properties of mesons. In section (IV) we shall present our results of present investigation and possible discussion on these results. Section (V) will summarize the present work.

II.   CHIRAL SU(3) MODEL

In this section we shall discuss the chiral SU(3) model to be used in the present work for evaluation of quark and gluon condensates in the strange hadronic medium. The basic theory of strong interaction, the QCD, is not directly applicable in the non-perturbative regime. To overcome this limitation the effective theories are constructed which are constrained by the basic properties like chiral symmetry and scale invariance of QCD. The chiral SU(3) model is one such effective model based on the non-linear realization and broken scale

invariance as well as spontaneous breaking properties of chiral symmetry. The glueball field χ is introduced in the model to account for the broken scale invariance properties of QCD. The model had been used successfully in the literature to study the properties of hadrons at finite density and temperature of the nuclear and strange hadronic medium. The general Lagrangian density of the chiral SU(3) model involve the kinetic energy terms, the baryon meson interactions, self interaction of vector mesons, scalar mesons-meson interactions as well as the explicit chiral symmetry breaking term and is written as

$$\mathcal{L} = \mathcal{L}_{kin} + \sum_{W=X,Y,V,A,u} \mathcal{L}_{BW} + \mathcal{L}_{vec} + \mathcal{L}_0 + \mathcal{L}_{SB} \tag{1}$$

The details of above Lagrangian density can be found in the reference [12].

From the Lagrangian densities of the chiral SU(3) model, using the mean field approximation, we find the coupled equations of motion for the scalar fields, σ, ζ, δ and the scalar dilaton field χ in the isospin asymmetric strange hadronic medium and these are

$$k_0\chi^2\sigma - 4k_1\left(\sigma^2 + \zeta^2 + \delta^2\right)\sigma - 2k_2\left(\sigma^3 + 3\sigma\delta^2\right) - 2k_3\chi\sigma\zeta$$
$$- \frac{d}{3}\chi^4\left(\frac{2\sigma}{\sigma^2 - \delta^2}\right) + \left(\frac{\chi}{\chi_0}\right)^2 m_\pi^2 f_\pi - \sum g_{\sigma i}\rho_i^s = 0 \tag{2}$$

$$k_0\chi^2\zeta - 4k_1\left(\sigma^2 + \zeta^2 + \delta^2\right)\zeta - 4k_2\zeta^3 - k_3\chi\left(\sigma^2 - \delta^2\right)$$
$$- \frac{d}{3}\frac{\chi^4}{\zeta} + \left(\frac{\chi}{\chi_0}\right)^2\left[\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right] - \sum g_{\zeta i}\rho_i^s = 0 \tag{3}$$

$$k_0\chi^2\delta - 4k_1\left(\sigma^2 + \zeta^2 + \delta^2\right)\delta - 2k_2\left(\delta^3 + 3\sigma^2\delta\right) + 2k_3\chi\delta\zeta$$
$$+ \frac{2}{3}d\chi^4\left(\frac{\delta}{\sigma^2 - \delta^2}\right) - \sum g_{\delta i}\rho_i^s = 0 \tag{4}$$

$$k_0\chi\left(\sigma^2 + \zeta^2 + \delta^2\right) - k_3\left(\sigma^2 - \delta^2\right)\zeta + \chi^3\left[1 + \ln\left(\frac{\chi^4}{\chi_0^4}\right)\right] + (4k_4 - d)\chi^3$$
$$- \frac{4}{3}d\chi^3\ln\left(\left(\frac{(\sigma^2 - \delta^2)\zeta}{\sigma_0^2\zeta_0}\right)\left(\frac{\chi}{\chi_0}\right)^3\right)$$
$$+ \frac{2\chi}{\chi_0^2}\left[m_\pi^2 f_\pi\sigma + \left(\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi\right)\zeta\right] = 0 \tag{5}$$

respectively. The values of parameter k_0, k_1, k_2, k_3, k_4 and d appearing in above equations are 2.54, 1.35, -4.78, -2.77, 0.22 and 0.064 respectively. These parameters of the model are

fitted so as to ensure extrema in the vacuum for the σ, ζ and χ field equations, to reproduce the vacuum masses of the η and η' mesons, the mass of the σ meson around 500 MeV, and, pressure, p(ρ_0)=0, with ρ_0 as the nuclear matter saturation density [12, 13]. The values of pion decay constant, f_π and kaon decay constant, f_K are 93.3 and 122 MeV respectively. The vacuum values of the scalar isoscalar fields, σ and ζ and the dilaton field χ are -93.3 MeV, -106.6 MeV and 409.8 MeV respectively. The values, $g_{\sigma N} = 10.6$ and $g_{\zeta N} = -0.47$ are determined by fitting to the vacuum baryon masses. The other parameters fitted to the asymmetric nuclear matter saturation properties in the mean-field approximation are: $g_{\omega N}$ = 13.3, $g_{\rho p} = 5.5$, $g_4 = 79.7$, $g_{\delta p} = 2.5$, $m_\zeta = 1024.5$ MeV, $m_\sigma = 466.5$ MeV and $m_\delta =$ 899.5 MeV. In equations (2) to (5), $\rho_i{}^s$ denote the scalar densities for the baryons and at zero temperature are given by expression,

$$\rho_i^s = \gamma_i \int \frac{d^3k}{(2\pi)^3} \frac{m_i^*}{E_i^*(k)}, \tag{6}$$

where, $E_i^*(k) = (k^2 + m_i^{*2})^{1/2}$, and, $\mu_i^* = \mu_i - g_{\omega i}\omega - g_{\rho i}\rho - g_{\phi i}\phi$, are the single particle energy and the effective chemical potential for the baryon of species i, and, γ_i=2 is the spin degeneracy factor [32].

In the present work, for the evaluation of vector and axial vector meson properties using QCD sum rules, we shall need the light quark condensates $\langle \bar{u}u \rangle$ and $\langle \bar{d}d \rangle$, the strange quark condensate $\langle \bar{s}s \rangle$ and the scalar gluon condensate $\langle \frac{\alpha_s}{\pi} G_{\mu\nu}^a G^{\mu\nu a} \rangle$. In the chiral effective model the explicit symmetry breaking term is introduced to eliminate the Goldstone bosons and can be used to extract the scalar quark condensates, $\langle q\bar{q} \rangle$ in terms of scalar fields σ, ζ, δ and χ. We write

$$\sum_i m_i \bar{q}_i q_i = -\mathcal{L}_{SB} \tag{7}$$

$$= \left(\frac{\chi}{\chi_0}\right)^2 \left(\frac{1}{2}m_\pi^2 f_\pi (\sigma + \delta) + \frac{1}{2}m_\pi^2 f_\pi (\sigma - \delta) + (\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi)\zeta\right). \tag{8}$$

From equation (8) light scalar quark condensates $\langle \bar{u}u \rangle$, $\langle \bar{d}d \rangle$ and strange quark condensate $\langle \bar{s}s \rangle$ can be written as

$$\langle \bar{u}u \rangle = \frac{1}{m_u} \left(\frac{\chi}{\chi_0}\right)^2 \left[\frac{1}{2}m_\pi^2 f_\pi (\sigma + \delta)\right], \tag{9}$$

$$\langle \bar{d}d \rangle = \frac{1}{m_d} \left(\frac{\chi}{\chi_0}\right)^2 \left[\frac{1}{2}m_\pi^2 f_\pi (\sigma - \delta)\right], \tag{10}$$

and

$$\langle \bar{s}s \rangle = \frac{1}{m_s} \left(\frac{\chi}{\chi_0} \right)^2 \left[(\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi)\zeta \right], \tag{11}$$

respectively.

As said earlier the scalar gluon condensates can be evaluated in the chiral effective model through the scalar dilaton field χ. The broken scale invariance property of QCD implies that the trace of energy momentum tensor is non zero (trace anomaly) and is equal to the scalar gluon condensates for massless QCD i.e.

$$T_\mu^\mu = \frac{\beta_{QCD}}{2g} G^a_{\ \mu\nu} G^{\mu\nu a} \tag{12}$$

We shall try to find the above trace of energy momentum tensor within chiral effective model. The trace anomaly property of QCD can be mimicked in the chiral effective model through the scale breaking Lagrangian density,

$$\mathcal{L}_{\text{scalebreaking}} = -\frac{1}{4}\chi^4 \ln\left(\frac{\chi^4}{\chi_0^4}\right) + \frac{d}{3}\chi^4 \ln\left(\left(\frac{I_3}{\det\langle X \rangle_0}\right)\left(\frac{\chi}{\chi_0}\right)^3\right), \tag{13}$$

where $I_3 = \det\langle X \rangle$, with X as the multiplet for the scalar mesons.

We write the energy momentum tensor for the dilaton field as,

$$T_{\mu\nu} = (\partial_\mu \chi)\left(\frac{\partial \mathcal{L}_\chi}{\partial(\partial^\nu \chi)}\right) - g_{\mu\nu}\mathcal{L}_\chi, \tag{14}$$

where the Lagrangian density for the dilaton field is,

$$\begin{aligned}
\mathcal{L}_\chi = {} & \frac{1}{2}(\partial_\mu \chi)(\partial^\mu \chi) - k_4 \chi^4 \\
& - \frac{1}{4}\chi^4 \ln\left(\frac{\chi^4}{\chi_0^4}\right) + \frac{d}{3}\chi^4 \ln\left(\left(\frac{(\sigma^2 - \delta^2)\zeta}{\sigma_0^2 \zeta_0}\right)\left(\frac{\chi}{\chi_0}\right)^3\right),
\end{aligned} \tag{15}$$

Multiplying equation (14) by $g^{\mu\nu}$, we obtain the trace of the energy momentum tensor within the chiral SU(3) model as

$$T_\mu^\mu = (\partial_\mu \chi)\left(\frac{\partial \mathcal{L}_\chi}{\partial(\partial_\mu \chi)}\right) - 4\mathcal{L}_\chi. \tag{16}$$

Using the Euler-Lagrange's equation for the χ field, the trace of the energy momentum tensor in the chiral SU(3) model can be expressed as [15, 33]

$$T_\mu^\mu = \chi \frac{\partial \mathcal{L}_\chi}{\partial \chi} - 4\mathcal{L}_\chi = -(1-d)\chi^4. \tag{17}$$

Comparing equations (12) and (17), we get the following relation between the scalar gluon condensates and the scalar dilaton field χ (in massless QCD),

$$\frac{\beta_{QCD}}{2g} G^a_{\ \mu\nu} G^{\mu\nu a} = -(1-d)\chi^4. \tag{18}$$

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In the case of finite quark masses, the trace of energy momentum tensor is written as,

$$T^\mu_\mu = \sum_i m_i \bar{q}_i q_i + \langle \frac{\beta_{QCD}}{2g} G^a_{\mu\nu} G^{\mu\nu a} \rangle \equiv -(1-d)\chi^4, \tag{19}$$

where the first term of the energy-momentum tensor, within the chiral SU(3) model is the negative of the explicit chiral symmetry breaking term, $\mathcal{L}_{SB}$ (see equation (8)).

The QCD β function at one loop level, for N_c colors and N_f flavors is given by

$$\beta_{\mathrm{QCD}}(g) = -\frac{11 N_c g^3}{48\pi^2}\left(1 - \frac{2N_f}{11 N_c}\right) + O(g^5) \tag{20}$$

In the above equation, the first term in the parentheses arises from the (antiscreening) self-interaction of the gluons and the second term, proportional to N_f, arises from the (screening) contribution of quark pairs.

The trace of the energy-momentum tensor in QCD, using the one loop beta function given by equation (20), for $N_c=3$ and $N_f=3$, and accounting for the finite quark masses [34] is given as,

$$T^\mu_\mu = -\frac{9}{8}\frac{\alpha_s}{\pi} G^a_{\ \mu\nu} G^{a\mu\nu} + \left(\frac{\chi}{\chi_0}\right)^2 \left(m_\pi^2 f_\pi \sigma + (\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi)\zeta\right). \tag{21}$$

Using equations (16) and (21), we can write

$$\left\langle \frac{\alpha_s}{\pi} G^a_{\ \mu\nu} G^{a\mu\nu} \right\rangle = \frac{8}{9}\left[(1-d)\chi^4 + \left(\frac{\chi}{\chi_0}\right)^2 \left(m_\pi^2 f_\pi \sigma + (\sqrt{2}m_k^2 f_k - \frac{1}{\sqrt{2}}m_\pi^2 f_\pi)\zeta\right)\right]. \tag{22}$$

We thus see from the equation (22) that the scalar gluon condensate $\left\langle \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^{\mu\nu a}\right\rangle$ is related to the dilaton field χ. For massless quarks, since the second term in (22) arising from explicit symmetry breaking is absent, the scalar gluon condensate becomes proportional to the fourth power of the dilaton field, χ, in the chiral SU(3) model.

III.   QCD SUM RULES FOR VECTOR AND AXIAL-VECTOR HEAVY MESONS IN STRANGE HADRONIC MATTER

In this section we shall discuss the QCD sum rules [10, 11] which will be used later along with the chiral SU(3) model for the evaluation of in-medium properties of vector and axial vector mesons in asymmetric strange hadronic matter. To find the mass modification of above discussed heavy mesons we shall use the two-point correlation function $\Pi_{\mu\nu}(q)$,

$$\Pi_{\mu\nu}(q) = i \int d^4x \ e^{iq\cdot x}\langle T\left\{J_\mu(x)J^\dagger_\nu(0)\right\}\rangle_{\rho_B}. \tag{23}$$

In above equation $J_\mu(x)$ denotes the isospin averaged current, $x = x^\mu = (x^0, \mathbf{x})$ is the four coordinate, $q = q^\mu = (q^0, \mathbf{q})$ is four momentum and T denotes the time ordered operation on the product of quantities in the brackets. From above definition it is clear that the two point correlation function is actually a Fourier transform of the expectation value of the time ordered product of two currents.

For the vector and axial vector mesons average particle-antiparticle currents are given by the expressions

$$J_\mu(x) \;=\; J_\mu^\dagger(x) = \frac{\bar{c}(x)\gamma_\mu q(x) + \bar{q}(x)\gamma_\mu c(x)}{2},$$

$$(24)$$

and

$$J_{5\mu}(x) \;=\; J_{5\mu}^\dagger(x) = \frac{\bar{c}(x)\gamma_\mu\gamma_5 q(x) + \bar{q}(x)\gamma_\mu\gamma_5 c(x)}{2}, \qquad (25)$$

respectively. Note that in above equations q denotes the u, d or s quark (depending upon type of meson under investigation) whereas c denotes the heavy charm quark (for B mesons c quark will be replaced by bottom b quark). Also note that in the present work, instead of considering the mass splitting between particles and antiparticles, we emphasize on the mass shift and mass-splitting of isospin doublet D (D^+, D^0) and B (B^+, B^0) mesons corresponding to both vector and axial vector mesons. To find the mass splitting of particles and antiparticles in the nuclear medium one has to consider the even and odd part of QCD sum rules [8]. For example, in ref. [8] the mass splitting between pseudoscalar D and $\bar{D}$ mesons was investigated using the even and odd QCD sum rules whereas in [9–11] the mass-shift of D mesons was investigated under centroid approximation.

At zero temperature the two point correlation function can be decomposed into the vacuum part and a static one-nucleon part i.e. we can write

$$\Pi_{\mu\nu}(q) \;=\; \Pi_{\mu\nu}^0(q) + \frac{\rho_B}{2M_N}T_{\mu\nu}^N(q), \qquad (26)$$

where

$$T_{\mu\nu}^N(\omega, \boldsymbol{q}) \;=\; i \int d^4x \, e^{iq\cdot x} \langle N(p)|T\left\{J_\mu(x)J_\nu^\dagger(0)\right\}|N(p)\rangle . \qquad (27)$$

In above equation $|N(p)\rangle$ denotes the isospin and spin averaged static nucleon state with the four-momentum $p = (M_N, 0)$. The state is normalized as $\langle N(\boldsymbol{p})|N(\boldsymbol{p}')\rangle = (2\pi)^3 2p_0 \delta^3(\boldsymbol{p}-\boldsymbol{p}')$.

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As discussed in Ref. [11], in the limit of the 3-vector $\boldsymbol{q} \to \boldsymbol{0}$, the correlation functions $T_N(\omega, \boldsymbol{q})$ can be related to the D^*N and D_1N scattering T-matrices. Thus we write [11]

$$\mathcal{T}_{D^*N}(M_{D^*}, 0) = 8\pi(M_N + M_{D^*})a_{D^*}$$

$$\mathcal{T}_{D_1N}(M_{D_1}, 0) = 8\pi(M_N + M_{D_1})a_{D_1} \tag{28}$$

In above equation a_{D^*} and a_{D_1} are the scattering lengths of D^*N and D_1N respectively. Near the pole positions of vector and axial vector mesons the phenomenological spectral densities can be parametrized with three unknown parameters a, b and c i.e. we write [9–11]

$$\begin{aligned}
\rho(\omega, 0) &= -\frac{f^2_{D^*/D_1}M^2_{D^*/D_1}}{\pi}\text{Im}\left[\frac{\mathcal{T}_{D^*/D_1N}(\omega, \boldsymbol{0})}{(\omega^2 - M^2_{D^*/D_1} + i\varepsilon)^2}\right] \\
&+ \cdots = a\,\frac{d}{d\omega^2}\delta'(\omega^2 - M^2_{D^*/D_1}) + b\,\delta(\omega^2 - M^2_{D^*/D_1}) + c\,\theta(\omega^2 - s_0)\,. \tag{29}
\end{aligned}$$

The term denoted by ... represent the continuum contributions. The first term denotes the double-pole term and corresponds to the on-shell effects of the T-matrices,

$$a = -8\pi(M_N + M_{D^*/D_1})a_{D^*/D_1}f^2_{D^*/D_1}M^2_{D^*/D_1}\,. \tag{30}$$

Now we shall write the relation between the scattering length of mesons and their in-medium mass-shift. For this first we note that the shift of squared mass of mesons can be written in terms of the parameter a appearing in equation (29) through relation [35],

$$\begin{aligned}
\Delta m^2_{D^*/D_1} &= \frac{\rho_B}{2M_N}\frac{a}{f^2_{D^*/D_1}M^2_{D^*/D_1}} \\
&= -\frac{\rho_B}{2M_N}8\pi(M_N + M_{D^*/D_1})a_{D^*/D_1}\,, \tag{31}
\end{aligned}$$

where in the last term we used equation (30). The mass shift is now defined by the relation

$$\delta m_{D^*/D_1} = \sqrt{m^2_{D^*/D_1} + \Delta m^2_{D^*/D_1}} - m_{D^*/D_1}. \tag{32}$$

The second term in equation (29) denotes the single-pole term, and corresponds to the off-shell (i.e. $\omega^2 \neq M^2_{D^*/D_1}$) effects of the T-matrices. The third term denotes the continuum term or the remaining effects, where, s_0, is the continuum threshold. The continuum threshold parameter s_0 define the scale below which the continuum contribution vanishes [36].

The shift in the decay constant of vector or axial vector mesons can be written as [29],

$$\delta f_{D^\star/D_1} = \frac{1}{2f_{D^\star/D_1}m_{D^\star/D_1}^2} \left(\frac{\rho_B}{2m_N}b - 2f_{D^\star/D_1}^2 m_{D^\star/D_1}\delta m_{D^\star/D_1} \right). \tag{33}$$

From equations (32) and (33) we observe that to find the value of mass shift and shift in decay constant of mesons we first need to find the value of unknown parameters a and b. These can be determined as follows: we note that in the low energy limit, $\omega \to 0$, the $T_N(\omega, \mathbf{0})$ is equivalent to the Born term $T^{\text{Born}}_{D^\star/D_1N}(\omega, \mathbf{0})$. We take into account the Born term at the phenomenological side,

$$\begin{aligned} T_N(\omega^2) &= T^{\text{Born}}_{D^\star/D_1N}(\omega^2) + \frac{a}{(M^2_{D^\star/D_1} - \omega^2)^2} \\ &+ \frac{b}{M^2_{D^\star/D_1} - \omega^2} + \frac{c}{s_0 - \omega^2}, \end{aligned} \tag{34}$$

with the constraint

$$\frac{a}{M^4_{D^\star/D_1}} + \frac{b}{M^2_{D^\star/D_1}} + \frac{c}{s_0} = 0. \tag{35}$$

Note that in Eq. (34) the phenomenological side of scattering amplitude for $q_\mu \neq 0$ is not exactly equal to Born term but there are contributions from other terms. However, for $\omega \to 0$, T_N on left should be equal to T^{Born} on right side of Eq. (34) and this requirement results in constraint given in Eq. (35). As we shall discuss below the constraint (35) help in eliminating the parameter c and scattering amplitude will be function of parameters a and b only. The Born terms to be used in equation (34) for vector and axial-vector mesons are given by following relations [10, 11]

$$\begin{aligned} T^{\text{Born}}_{D^*N}(\omega, \mathbf{0}) &= \frac{2f_{D^*}^2 M_{D^*}^2 M_N(M_H + M_N)g_{D^*NH}^2}{[\omega^2 - (M_H + M_N)^2][\omega^2 - M_{D^*}^2]^2}, \\ T^{\text{Born}}_{D_1N}(\omega, \mathbf{0}) &= \frac{2f_{D_1}^2 M_{D_1}^2 M_N(M_H - M_N)g_{D_1NH}^2}{[\omega^2 - (M_H - M_N)^2][\omega^2 - M_{D_1}^2]^2}. \end{aligned} \tag{36}$$

In the above equations $g_{D^\star NH}$ and g_{D_1NH} are the coupling constants. M_H is the the mass of the hadron e.g. corresponding to charm mesons we have Λ_c and Σ_c whereas corresponding to bottom mesons we have the hadrons Λ_b and Σ_b. Corresponding to charm mesons we take the average value of the masses of M_{Λ_c} and M_{Σ_c} and is equal to 2.4 GeV. For the case of mesons having bottom quark, b, we consider the average value of masses of Λ_b and Σ_b and it is equal to 5.7 GeV [11, 29].

Now we write the equation for the Borel transformation of the scattering matrix on the phenomenological side and equate that to the Borel transformation of the scattering matrix for the operator expansion side. For vector meson, D^*, the Borel transformation equation is given by [11],

$$
a\left\{\frac{1}{M^2}e^{-\frac{M_{D^*}^2}{M^2}} - \frac{s_0}{M_{D^*}^4}e^{-\frac{s_0}{M^2}}\right\} + b\left\{e^{-\frac{M_{D^*}^2}{M^2}} - \frac{s_0}{M_{D^*}^2}e^{-\frac{s_0}{M^2}}\right\}
$$

$$
+ B\left[\frac{1}{(M_H + M_N)^2 - M_{D^*}^2} - \frac{1}{M^2}\right]e^{-\frac{M_{D^*}^2}{M^2}} - \frac{B}{(M_H + M_N)^2 - M_{D^*}^2}e^{-\frac{(M_H+M_N)^2}{M^2}}
$$

$$
= \left\{-\frac{m_c\langle\bar{q}q\rangle_N}{2} - \frac{2\langle q^\dagger iD_0 q\rangle_N}{3} + \frac{m_c^2\langle q^\dagger iD_0 q\rangle_N}{M^2}\right\}e^{-\frac{m_c^2}{M^2}} + \frac{m_c\langle\bar{q}g_s\sigma Gq\rangle_N}{3M^2}e^{-\frac{m_c^2}{M^2}}
$$

$$
+ \left\{\frac{8m_c\langle\bar{q}iD_0 iD_0 q\rangle_N}{3M^2} - \frac{m_c^3\langle\bar{q}iD_0 iD_0 q\rangle_N}{M^4}\right\}e^{-\frac{m_c^2}{M^2}}
$$

$$
- \frac{1}{24}\langle\frac{\alpha_s GG}{\pi}\rangle_N \int_0^1 dx\left(1 + \frac{\widetilde{m}_c^2}{2M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}
$$

$$
+ \frac{1}{48M^2}\langle\frac{\alpha_s GG}{\pi}\rangle_N \int_0^1 dx\frac{1-x}{x}\left(\widetilde{m}_c^2 - \frac{\widetilde{m}_c^4}{M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}. \tag{37}
$$

where, $B = \frac{2f_{D^*}^2 M_{D^*}^2 M_N(M_H + M_N)g_{D^* NH}^2}{(M_H + M_N)^2 - M_{D^*}^2}$. Note that in equation (37) we have two unknown parameters a and b. We differentiate equation (37) w.r.t. $\frac{1}{M^2}$ so that we could have two equations and two unknowns. By solving those two coupled equations we will be able to get the values of parameters a and b. Same procedure will be applied to obtain the values of parameters a and b corresponding to axial-vector mesons. For the axial-vector mesons, D_1, the Borel transformation equation is given by [11],

$$
a\left\{\frac{1}{M^2}e^{-\frac{M_{D_1}^2}{M^2}} - \frac{s_0}{M_{D_1}^4}e^{-\frac{s_0}{M^2}}\right\} + b\left\{e^{-\frac{M_{D_1}^2}{M^2}} - \frac{s_0}{M_{D_1}^2}e^{-\frac{s_0}{M^2}}\right\}
$$

$$
+ C\left[\frac{1}{(M_H - M_N)^2 - M_{D_1}^2} - \frac{1}{M^2}\right]e^{-\frac{M_{D_1}^2}{M^2}} - \frac{C}{(M_H - M_N)^2 - M_{D_1}^2}e^{-\frac{(M_H-M_N)^2}{M^2}}
$$

$$
= \left\{\frac{m_c\langle\bar{q}q\rangle_N}{2} - \frac{2\langle q^\dagger iD_0 q\rangle_N}{3} + \frac{m_c^2\langle q^\dagger iD_0 q\rangle_N}{M^2}\right\}e^{-\frac{m_c^2}{M^2}} - \frac{m_c\langle\bar{q}g_s\sigma Gq\rangle_N}{3M^2}e^{-\frac{m_c^2}{M^2}}
$$

$$
- \left\{\frac{8m_c\langle\bar{q}iD_0 iD_0 q\rangle_N}{3M^2} - \frac{m_c^3\langle\bar{q}iD_0 iD_0 q\rangle_N}{M^4}\right\}e^{-\frac{m_c^2}{M^2}}
$$

$$
- \frac{1}{24}\langle\frac{\alpha_s GG}{\pi}\rangle_N \int_0^1 dx\left(1 + \frac{\widetilde{m}_c^2}{2M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}
$$

$$
+ \frac{1}{48M^2}\langle\frac{\alpha_s GG}{\pi}\rangle_N \int_0^1 dx\frac{1-x}{x}\left(\widetilde{m}_c^2 - \frac{\widetilde{m}_c^4}{M^2}\right)e^{-\frac{\widetilde{m}_c^2}{M^2}}, \tag{38}
$$

where, $C = \frac{2f_{D_1}^2 M_{D_1}^2 M_N(M_H - M_N)g_{D_1 NH}^2}{(M_H - M_N)^2 - M_{D_1}^2}$. In the above equations $\widetilde{m}_c^2 = \frac{m_c^2}{x}$.

As discussed earlier, in determining the properties of hadrons from QCD sum rules, we shall use the values of quark and gluon condensates as calculated using chiral SU(3) model. Any operator $\mathcal{O}$ on OPE side can be written as [35–37],

$$
\begin{aligned}
\mathcal{O}_{\rho_B} &= \mathcal{O}_{vacuum} + 4 \int \frac{d^3p}{(2\pi)^3 2E_p} n_F \langle N(p)|\mathcal{O}|N(p)\rangle \\
&= \mathcal{O}_{vacuum} + \frac{\rho_B}{2M_N}\mathcal{O}_N
\end{aligned}
\tag{39}
$$

In above equation, $\mathcal{O}_{\rho_B}$, gives us the expectation value of the operator at finite baryonic density. The term $\mathcal{O}_{vacuum}$ stands for the vacuum expectation value of the operator and $\mathcal{O}_N$ gives us the nucleon expectation value of the operator. Thus within chiral SU(3) model, we can find the values of $\mathcal{O}_{\rho_B}$ at finite density of the nuclear medium and hence can find $\mathcal{O}_N$ using

$$
\mathcal{O}_N = [\mathcal{O}_{\rho_B} - \mathcal{O}_{vacuum}]\frac{2M_N}{\rho_B}.
\tag{40}
$$

The scalar quark condensates $\langle \bar{q}q \rangle$ in equations (37) and (38) are evaluated using equations (9), (10) and (11). The condensate $\langle \bar{q}g_s\sigma Gq\rangle_{\rho_B}$ is given by the equation [38],

$$
\langle \bar{q}g_s\sigma Gq\rangle_{\rho_B} = \lambda^2 \langle \bar{q}q\rangle_{\rho_B} + 3.0GeV^2\rho_B.
\tag{41}
$$

Also we write [38],

$$
\langle \bar{q}iD_0iD_0q\rangle_{\rho_B} + \frac{1}{8}\langle \bar{q}g_s\sigma Gq\rangle_{\rho_B} = 0.3GeV^2\rho_B.
\tag{42}
$$

As discussed above the quark condensate, $\langle \bar{q}q\rangle_{\rho_B}$, can be calculated within the chiral SU(3) model. This value of $\langle \bar{q}q\rangle_{\rho_B}$ can be used through equations (41) and (42) to calculate the value of condensates $\langle \bar{q}g_s\sigma Gq\rangle_{\rho_B}$ and $\langle \bar{q}iD_0iD_0q\rangle_{\rho_B}$ within chiral SU(3) model. The value of quark condensate $\langle q^\dagger iD_0q\rangle$ for light quark is equal to $0.18GeV^2\rho_B$ and for strange quark it is $0.018GeV^2\rho_B$ [38].

It may be noted that the QCD sum rules for the evaluation of in-medium properties of vector mesons, B^* and axial vector mesons B_1, can be written by replacing masses of charmed mesons D^* and D_1, by corresponding masses of bottom mesons B^* and B_1 in equations (37) and (38) respectively. Also the bare charm quark mass, m_c will be replaced by the mass of bottom quark, m_b.

IV. RESULTS AND DISCUSSIONS

In this section we shall discuss the results of present investigation of in-medium mass shift and shift in decay constant of vector $(D^\star(D^{+\star}, D^{0\star}, D_s^\star)$ and $B^\star(B^{+\star}, B^{0\star}, B_s^\star))$ and axial vector $(D_1(D_1^+, D_1^0, D_{1s})$ and $B_1(B_1^+, B_1^0, B_{1s}))$ mesons in isospin asymmetric strange hadronic matter. First we list the values of various parameters used in the present work on vector and axial vector mesons. Nuclear matter saturation density adopted in the present investigation is 0.15 fm^{-3}. The value of coupling constants $g_{D^*N\Lambda_c} \approx g_{D^*N\Sigma_c} \approx g_{D_1N\Lambda_c} \approx g_{D_1N\Sigma_c} \approx g_{B^*N\Lambda_c} \approx g_{B^*N\Sigma_c} \approx g_{B_1N\Lambda_c} \approx g_{B_1N\Sigma_c}$ is 3.86 [11]. The masses of different mesons $M_{D^{*+}}, M_{D^{*0}}, M_{B^{*+}}, M_{B^{*0}}, M_{D_1^+}, M_{D_1^0}, M_{B_1^+}, M_{B_1^0}, M_{D_s^*}, M_{B_s^*}, M_{D_{1s}}$ and $M_{B_{1s}}$ used in this present investigation are 2.01, 2.006, 5.325, 5.325, 2.423, 2.421, 5.721, 5.723, 2.112, 5.415, 2.459 and 5.828 GeV respectively. The values of decay constants $f_{D^*}, f_{B^*}, f_{D_1}, f_{B_1}, f_{D_s^*}, f_{B_s^*}, f_{D_{1s}}$ and $f_{B_{1s}}$ are 0.270, 0.195, 0.305, 0.255, 1.16*(0.270), 1.16*(0.195), 1.16*(0.305) and 1.16*(0.255) GeV respectively. The masses of quarks namely up, u, down, d, strange, s, charm, c, and bottom, b, used in the present work are 0.005, 0.007, 0.105, 1.4 and 2.3 GeV respectively. The values of threshold parameter s_0 for D^*, B^*, D_1, B_1, D_s^*, B_s^*, D_{1s} and B_{1s} mesons are taken as 6.5, 35, 8.5, 39, 7.5, 38, 9.5 and 41 GeV^2 respectively. The various coupling constants and continuum threshold parameters s_0 are not subjected to medium modifications. To describe the exact mass(decay) shift of above mesons we have chosen a suitable Borel window i.e. the range of squared Borel mass parameter, M^2, within which there is almost no variation in the mass and decay constant. In table (I) we mention the Borel windows as observed in the present calculations for the mass shift and shift in decay constant of vector and axial vector mesons.

We start with the discussion on the behaviour of quark and gluon condensates for different strangeness fractions and isospin asymmetry parameters of strange hadronic medium. In literature, the quark condensates are evaluated to leading order in nuclear density using the Feynman Hellmann theorem and model independent results were obtained in terms of pion nucleon sigma term [34, 39]. Using the Feynman Hellmann theorem, the quark condensate at finite density of nuclear matter is expressed as sum of vacuum value and a term dependent on energy density of nuclear matter. In model independent calculations the interactions between nucleons were neglected and free space nucleon mass was used. If one use only the leading order calculations for the evaluation of quark condensates above nuclear matter

	$\delta m_{D^{*+}}$	$\delta m_{D^{*0}}$	$\delta m_{D_s^*}$	$\delta m_{B^{*+}}$	$\delta m_{B^{*0}}$	$\delta m_{B_s^*}$
M^2 (GeV^2)	(4.5 - 6.5)	(4.5 - 6.5)	(5.0 - 7.0)	(30 - 33)	(30 - 33)	(31 - 34)
	$\delta f_{D^{*+}}$	$\delta f_{D^{*0}}$	$\delta f_{D_s^*}$	$\delta f_{B^{*+}}$	$\delta f_{B^{*0}}$	$\delta f_{B_s^*}$
M^2 (GeV^2)	(3.3 - 4.9)	(3.3 - 4.9)	(3.8 - 5.3)	(26 - 31)	(26 - 31)	(27 - 31)
	$\delta m_{D_1^+}$	$\delta m_{D_1^0}$	$\delta m_{D_{1s}}$	$\delta m_{B_1^+}$	$\delta m_{B_1^0}$	$\delta m_{B_{1s}}$
M^2 (GeV^2)	(5.4 - 9.4)	(5.4 - 9.4)	(5.9 - 9.9)	(33 - 38)	(33 - 38)	(36 - 40)
	$\delta f_{D_1^+}$	$\delta f_{D_1^0}$	$\delta f_{D_{1s}}$	$\delta f_{B_1^+}$	$\delta f_{B_1^0}$	$\delta f_{B_{1s}}$
M^2 (GeV^2)	(4.2 - 7.2)	(4.2 - 7.2)	(5.0 - 8.0)	(30 - 34)	(30 - 34)	(32 - 36)

TABLE I: In the above table we mention the Borel windows as observed for mass shift and shift in decay constant of vector and axial vector mesons.

density then the quark condensates decreases very sharply and almost vanishes around $3\rho_0$. In ref. [40] Dirac-Brueckner approach with the Bonn boson-exchange potential was used to include the higher order corrections and to find the quark condensates in the nuclear matter above the nuclear matter density. The calculations show that at higher density the quark condensate decrease more slowly as compared to leading order predictions. In the chiral model used in the present work the quark and gluon condensates are expressed in terms of scalar fields σ, ζ, δ and χ (see equations (9), (10) (11) and (22)). The scalar fields σ, ζ, δ and χ in the strange hadronic medium are evaluated by solving the coupled equations (2), (3), (4) and (5). In figure (1) we show the variation of ratio of in-medium value to vacuum value of scalar fields as a function of baryonic density of strange hadronic medium. We show the results for isospin asymmetry parameter $\eta = 0$ and 0.5. For each value of η, the results are shown for strangeness fractions, $f_s = 0$, 0.3 and 0.5. From figure one can see that the scalar field σ and ζ varies considerably as a function of baryonic density of medium whereas the scalar field χ has little density dependence. For example, in symmetric nuclear medium ($\eta = 0$ and $f_s = 0$), at density $\rho_B = \rho_0$ ($4\rho_0$) the values of scalar fields σ, ζ and χ are observed to be 0.64 σ_0 (0.31 σ_0), 0.91 ζ_0 (0.86 ζ_0), and 0.99 χ_0 (0.97 χ_0). The symbols σ_0, ζ_0 and χ_0 denote the vacuum values of scalar fields and have values -93.29, -106.75 and -409.76 MeV respectively. From figure (1) we observe that at high baryon density the strange scalar-isoscalar field ζ varies considerably as a function of strangeness fraction as

compared to non-strange scalar isoscalar field σ. For example, in symmetric medium ($\eta = 0$), at baryon density $4\rho_0$, as we move from $f_s = 0$ to $f_s = 0.5$, the value of ζ changes by 14 %, whereas the value of σ changes by 1% only. However, the effect of isospin asymmetry of the medium is more on the values of σ field as compared to ζ field. For example, in nuclear medium ($f_s = 0$), at baryon density $\rho_B = 4\rho_0$, as we move from $\eta = 0$ to 0.5 the values of non-strange scalar field, σ and the strange scalar field, ζ changes by 10.25% and 0.24 % respectively. However, in strange medium, at $f_s = 0.5$, the percentage change in the values of σ and ζ is 7.2% and 7% respectively. Since the scalar meson, σ has light quark content (u and d quarks) and the ζ meson have strange quark contents (s quark) and therefore former is more sensitive to isospin asymmetry of the medium (property of u and d quarks) and the latter is to strangeness fraction of the medium.

In figure (2) we show the variation of ratio of in-medium value of quark condensate to the vacuum value of condensate as a function of baryonic density of hadronic medium for different values of strangeness fractions f_s and isospin asymmetry parameter η. We show the results for light quark condensates $\langle \bar{u}u \rangle$ and $\langle \bar{d}d \rangle$ as well as for the strange quark condensate $\langle \bar{s}s \rangle$. We observe that for given value of isospin asymmetry parameter, η, and strangeness fraction, f_s, the magnitude of the values of quark condensate decreases w.r.t. vacuum value. For example, in symmetric nuclear matter ($\eta = 0$ and $f_s = 0$), at nuclear saturation density, $\rho_B = \rho_0$, the values of $\langle \bar{u}u \rangle$, $\langle \bar{d}d \rangle$ and $\langle \bar{s}s \rangle$ are observed to be 0.629 $\langle \bar{u}u \rangle_0$, 0.629 $\langle \bar{d}d \rangle_0$ and 0.895 $\langle \bar{s}s \rangle_0$ respectively. Note that $\langle \bar{u}u \rangle_0$, $\langle \bar{d}d \rangle_0$ and $\langle \bar{s}s \rangle_0$ denotes the vacuum values of quark condensates and in chiral SU(3) model these are -1.401×10^{-2} GeV^3 and -1.401×10^{-2} GeV^3 and -4.671×10^{-2} GeV^3 respectively. As we can see from equations (9), (10) and (11), the values of quark condensates are proportional to the scalar fields σ and ζ. As discussed above the magnitude of these scalar fields undergo drop as a function of density of baryonic matter and this further cause a decrease in the magnitude of quark condensates. As we move to the asymmetric nuclear matter, say $\eta = 0.5$ and $f_s = 0$, the values of $\langle \bar{u}u \rangle$, $\langle \bar{d}d \rangle$ and $\langle \bar{s}s \rangle$, at nuclear saturation density, ρ_0, are observed to be 0.669 $\langle \bar{u}u \rangle_0$, 0.607 $\langle \bar{d}d \rangle_0$ and 0.897 $\langle \bar{s}s \rangle_0$ respectively. Note that as we move to the asymmetric medium the values of condensate $\langle \bar{u}u \rangle$ increases whereas that of $\langle \bar{d}d \rangle$ decreases due opposite contribution of scalar-isovector mesons δ.

In isospin symmetric medium ($\eta = 0$), below baryon density $\rho_B = 3.3\rho_0$ as we move from non-strange medium, i.e. $f_s = 0$, to strange medium with $f_s = 0.5$, the magnitude of light
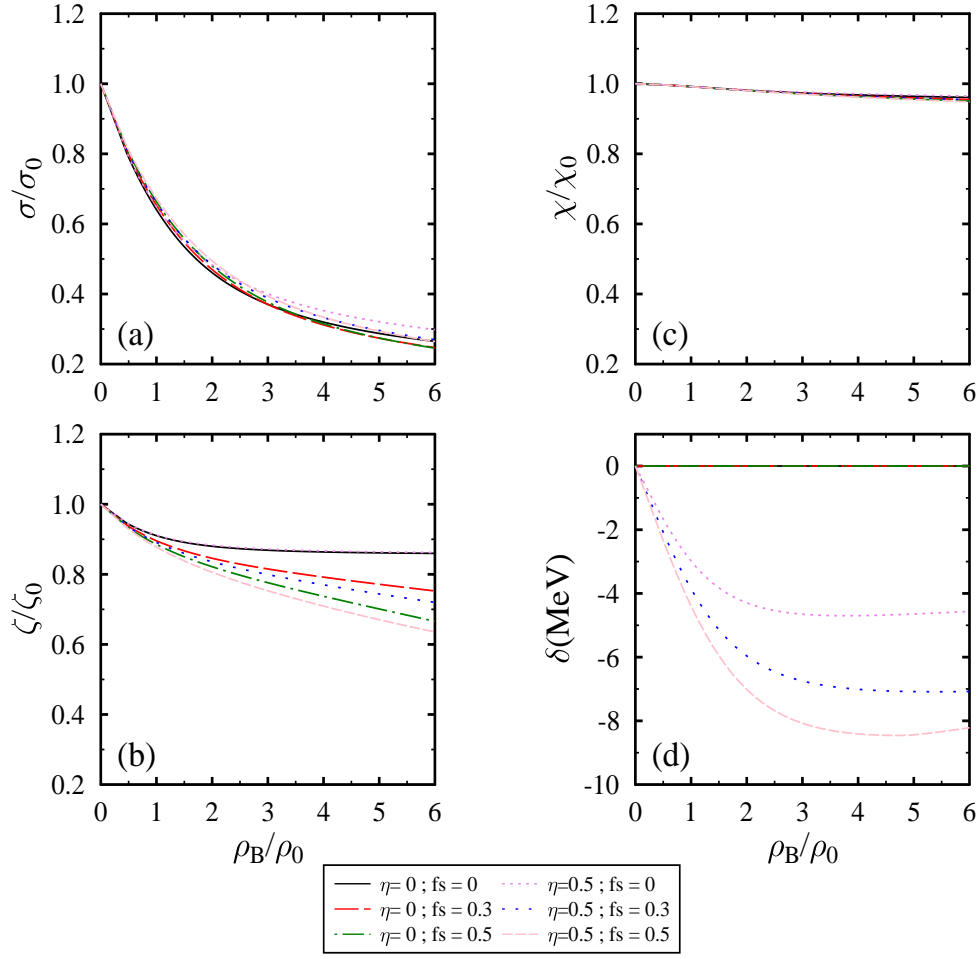
FIG. 1: (Color online) In above figure, subplots (a), (b) and (c) show the variation of ratio of in-medium value to vacuum value of scalar fields, σ/σ_0, ζ/ζ_0 and χ/χ_0 as a function of baryonic density, ρ_B (in units of nuclear saturation density, ρ_0). In subplot (d) we have shown the scalar-isovector field δ as a function of density of medium. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions f_s =0, 0.3 and 0.5.

quark condensates $\langle \bar{u}u \rangle$ increases. At baryon density ρ_0 the values of quark condensate $\langle \bar{u}u \rangle$ are observed to be 0.63 $\langle \bar{u}u \rangle_0$, 0.643 $\langle \bar{u}u \rangle_0$ and 0.652 $\langle \bar{u}u \rangle_0$ at strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. Above baryon density $\rho_B = 3.3\,\rho_0$ the magnitude of the values of light quark condensates is more in non strange medium ($f_s = 0$) as compared to strange medium with finite f_s. At density $4\rho_0$ these values of quark condensates changes to 0.3 $\langle \bar{u}u \rangle_0$,
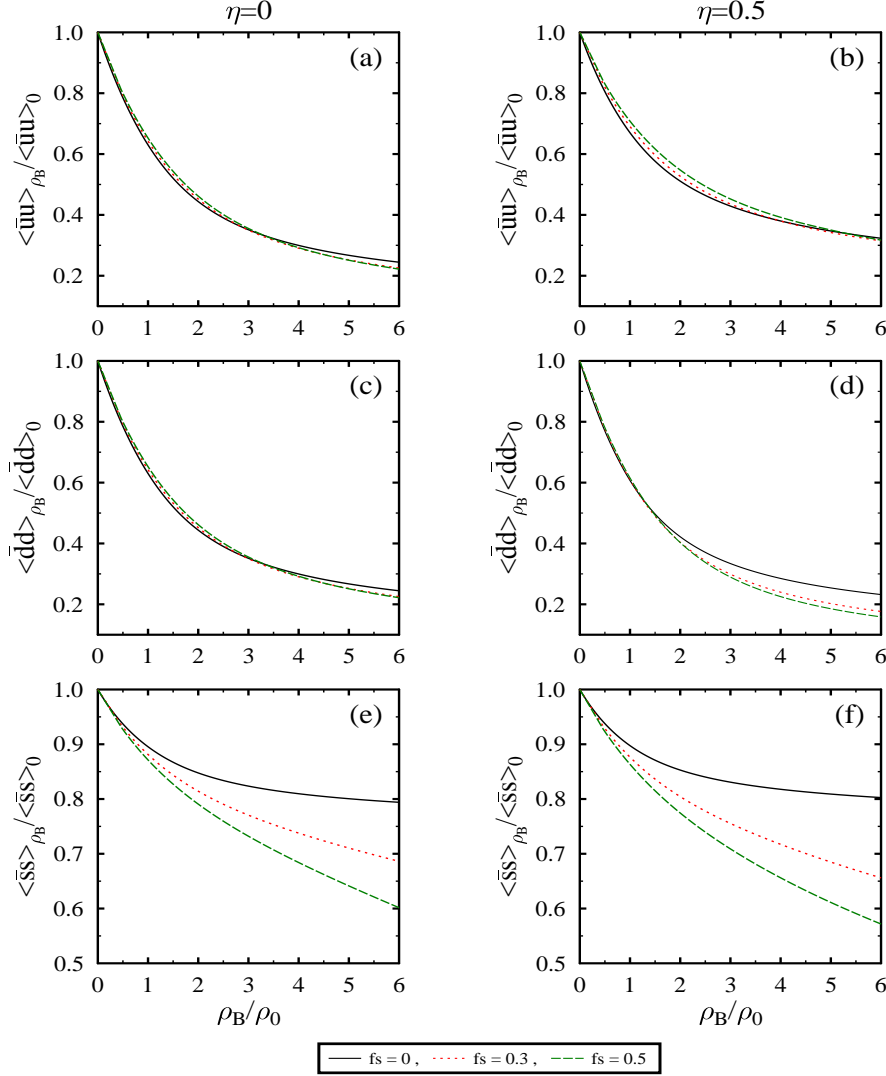
FIG. 2: (Color online) In above figure we plot the ratio of in-medium quark condensate to vacuum condensate as a function of baryonic density, ρ_B (in units of nuclear saturation density, ρ_0). We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s =0$, 0.3 and 0.5.

0.291 $\langle \bar{u}u \rangle_0$ and 0.292 $\langle \bar{u}u \rangle_0$ respectively. In isospin asymmetric matter with $\eta = 0.5$ and baryon density, $\rho_B = \rho_0$ the values of light quark condensates $\langle \bar{u}u \rangle$ are observed to be 0.669 $\langle \bar{u}u \rangle_0$, 0.691 $\langle \bar{u}u \rangle_0$ and 0.708 $\langle \bar{u}u \rangle_0$ at strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. At baryon density $4\rho_0$ these values of condensates changes to 0.38 $\langle \bar{u}u \rangle_0$, 0.379 $\langle \bar{u}u \rangle_0$ and

0.392 $\langle \bar{u}u \rangle_0$ respectively. The values of light quark condensates $\langle \bar{d}d \rangle$, in asymmetric matter with $\eta = 0.5$ and baryon density $\rho_B = \rho_0$ ($4\rho_0$), are observed to be 0.607 $\langle \bar{d}d \rangle_0$ (0.285 $\langle \bar{d}d \rangle_0$), 0.609 $\langle \bar{d}d \rangle_0$ (0.239 $\langle \bar{d}d \rangle_0$) and 0.615 $\langle \bar{d}d \rangle_0$ (0.225 $\langle \bar{d}d \rangle_0$) at strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. From figure (2) we observe that as a function of density of baryonic matter we always observe a decrease in the values of quark condensates. This support the expectation of chiral symmetry restoration at high baryonic density. However, in linear Walecka model [41, 42] and also in Dirac-Brueckner approach [40], the values of quark condensates are observed to increase at higher values of baryonic density and causes hindrance to chiral symmetry restoration. The possible reason for this may be that the chiral invariance property was not considered in these calculations [40]. As the strange quark condensates, $\langle \bar{s}s \rangle$, is proportional to the strange scalar-isoscalar field, ζ, therefore the behavior of this field as a function of various parameters of the medium is also reflected in the values of strange quark condensate $\langle \bar{s}s \rangle$. For fixed baryon density, ρ_B and isospin asymmetry parameter, η, as we move from non-strange to strange hadronic medium the values of strange condensate decreases. For example, at nuclear saturation density, ρ_0 and isospin asymmetric parameter $\eta = 0$ (0.5), the values of $\langle \bar{s}s \rangle$ are observed to be 0.895 $\langle \bar{s}s \rangle_0$ (0.897 $\langle \bar{s}s \rangle_0$), 0.881 $\langle \bar{s}s \rangle_0$ (0.877 $\langle \bar{s}s \rangle_0$)and 0.871 $\langle \bar{s}s \rangle_0$ (0.863 $\langle \bar{s}s \rangle_0$) at $f_s = 0$, 0.3 and 0.5 respectively. At baryonic density $4\rho_0$ and isospin asymmetric parameter $\eta = 0$ (0.5), the values of $\langle \bar{s}s \rangle$ are observed to be 0.810 $\langle \bar{s}s \rangle_0$ (0.818 $\langle \bar{s}s \rangle_0$), 0.738 $\langle \bar{s}s \rangle_0$ (0.717 $\langle \bar{s}s \rangle_0$)and 0.684 $\langle \bar{s}s \rangle_0$ (0.656 $\langle \bar{s}s \rangle_0$) at $f_s = 0$, 0.3 and 0.5 respectively.

In figure (3) we show the dependence of Gluon condensates on the density and isospin asymmetry of strange hadronic medium. We plot the variation of in-medium gluon condensate to vacuum condensate ratio as a function of baryonic density of strange hadronic medium. In subfigures (a) and (b) we consider the contribution of finite quark mass term in the calculation of gluon condensates whereas subfigures (c) and (d) are without the effect of quark mass term (see equation (21)). We observe that as a function of baryonic density of the hadronic medium the values of gluon condensates decreases. Considering the effect of finite quark mass term, at baryonic density, $\rho_B = \rho_0$, and isospin asymmetric parameter, η = 0 (0.5), the values of gluon condensates are observed to be 0.985 G_{vac} (0.986 G_{vac}), 0.988 G_{vac} (0.989 G_{vac}) and 0.990 G_{vac} (0.991 G_{vac}) at strangeness fractions, $f_s = 0$, 0.3 and 0.5 respectively. However if we do not take into account the finite quark mass term then for baryonic density, $\rho_B = \rho_0$, and isospin asymmetric parameter, $\eta = 0$ (0.5), the values of
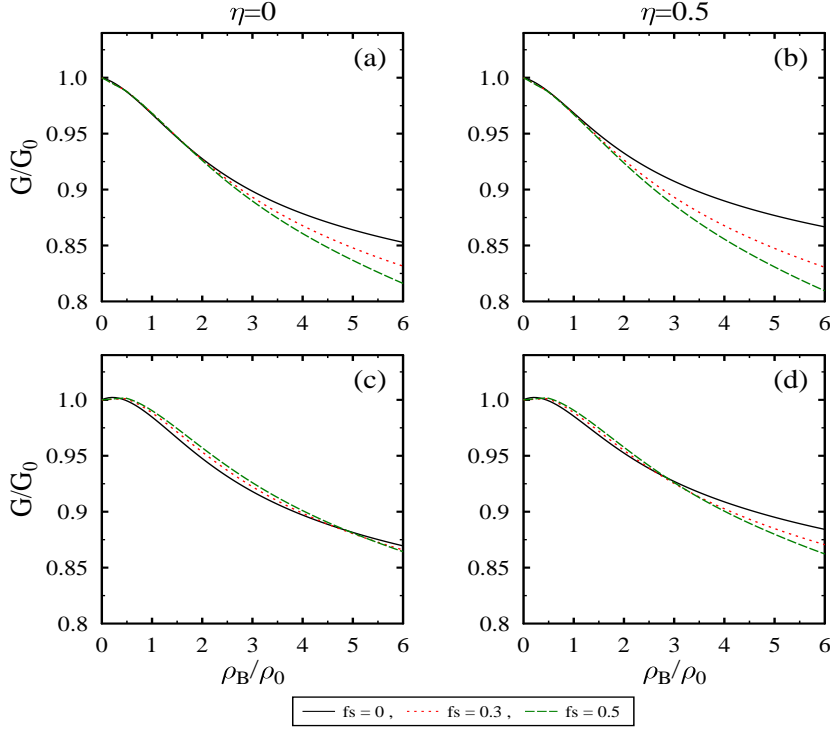
FIG. 3: (Color online) In above figure we plot the ratio of in-medium scalar gluon condensate to vacuum value of gluon condensate as a function of baryonic density, ρ_B (in units of nuclear saturation density, ρ_0). We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5. In y-axis $G = \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^{\mu\nu a}$.

gluon condensates are observed to be 0.967 G_{vac} (0.968 G_{vac}), 0.968 G_{vac} (0.968 G_{vac}) and 0.968 G_{vac} (0.967 G_{vac}) at strangeness fractions, $f_s = 0$, 0.3 and 0.5 respectively. As one can see from figures (c) and (d), the effect of strangeness fractions are more pronounced at higher baryon densities. For example, at $\rho_B = 4\rho_0$, and isospin asymmetry parameter, $\eta = 0$ (0.5), the values of gluon condensates are observed to be 0.879 G_{vac} (0.890 G_{vac}), 0.868 G_{vac} (0.868 G_{vac}) and 0.861 G_{vac} (0.856 G_{vac}) at strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. The above calculations show that the gluon condensates have small density dependence as compared to quark condensates. This observation is consistent with earlier model independent calculations by Cohen [34] and also with the QMC model calculation in ref. [43].

In figures (4) and (5) we show the variation of mass shift and shift in decay constant

respectively of $D^{\star+}$ and $D^{\star 0}$ vector mesons as a function of squared Borel mass parameter, M^2. In each subplot we compare the results at $\eta = 0$ ($f_s = 0$, 0.3 and 0.5) with $\eta = 0.5$ (f_s = 0, 0.3 and 0.5). We present the results at baryon densities, $\rho_B = \rho_0$, $2\rho_0$ and $4\rho_0$.

In symmetric nuclear medium, at nuclear saturation density $\rho_B = \rho_0$, the values of mass shifts for $D^{*+}(D^{*0})$ vector mesons are observed to be -63.8(-92.59) , -76(-111) and -74(-108) MeV for strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. The difference in the masses of D^{*+} and D^{*0} mesons in the symmetric nuclear medium is due to the different masses of u and d quarks considered in the present investigation. For asymmetric medium($\eta = 0.5$) and baryonic density, $\rho_B = \rho_0$, the above values of mass shift changes to -68.4(-81), -84.4(-93.9) and -83.6(-88.5) MeV for strangeness fractions, $f_s = 0$, 0.3 and 0.5 respectively. From the above quoted values on mass shift we conclude that for given value of baryonic density and strangeness fraction, D^{*+} (D^{*0}) mesons undergo large (less) mass drop in asymmetric medium as compared to symmetric medium. Note that the D^{*+} meson contain the light d quark and the D^{*0} meson has light u quark. As discussed earlier the behavior of $\left\langle \bar{d}d \right\rangle$ and $\langle \bar{u}u \rangle$ condensates is opposite as a function of asymmetry of the medium and this causes the observed behavior of D^{*+} and D^{*0} mesons as a function of asymmetry of the medium. As compared to nuclear medium ($f_s = 0$) the drop in the masses of D^{*+} and D^{*0} mesons is more in strange medium (finite f_s). In symmetric nuclear medium, at baryon density $\rho_B = 2\rho_0$ ($4\rho_0$), the values of mass shift for D^{*+} mesons are found to be -92.3(-104.2) , -96.9(-106.25) and -95.4(-106.19) MeV for strangeness fractions $f_s = 0$,0.3 and 0.5 respectively. In asymmetric matter with η=0.5 the above values are shifted to -96.7(-107.5), -107(-116.5) and -108(-119.6) for strangeness fraction $f_s = 0$,0.3 and 0.5 respectively. At baryon density $\rho_B = 2\rho_0$ ($4\rho_0$), and $\eta = 0.5$, the values of mass shift for D^{*0} mesons are found to be -117(-137), -121(-138.7) and -116 (-135.6) MeV for strangeness fraction $f_s = 0$,0.3 and 0.5 respectively. The drop in the masses of D^{*+} and D^{*0} mesons increases with increase in the baryonic density of the medium.

Now we come to the behavior of decay constants of D^{*+} and D^{*0} mesons in strange hadronic medium. In symmetric nuclear matter ($\eta = 0$) for baryon density, $\rho_B = \rho_0$, the values of shift in decay constants of D^{*+} (D^{*0}) mesons are observed to be -20(-22), -28.2(-28.9) and -28.1(-28.8) MeV for the values of strangeness fractions $f_s = 0$, 0.3, 0.5 respectively. For asymmetry parameter, η=0.5, the above values of shift in decay constants changes to -20.6(-20.7), -28.4(-28.3) and -28.4(-28.1) MeV. For density, $2\rho_0$, and $\eta = 0$
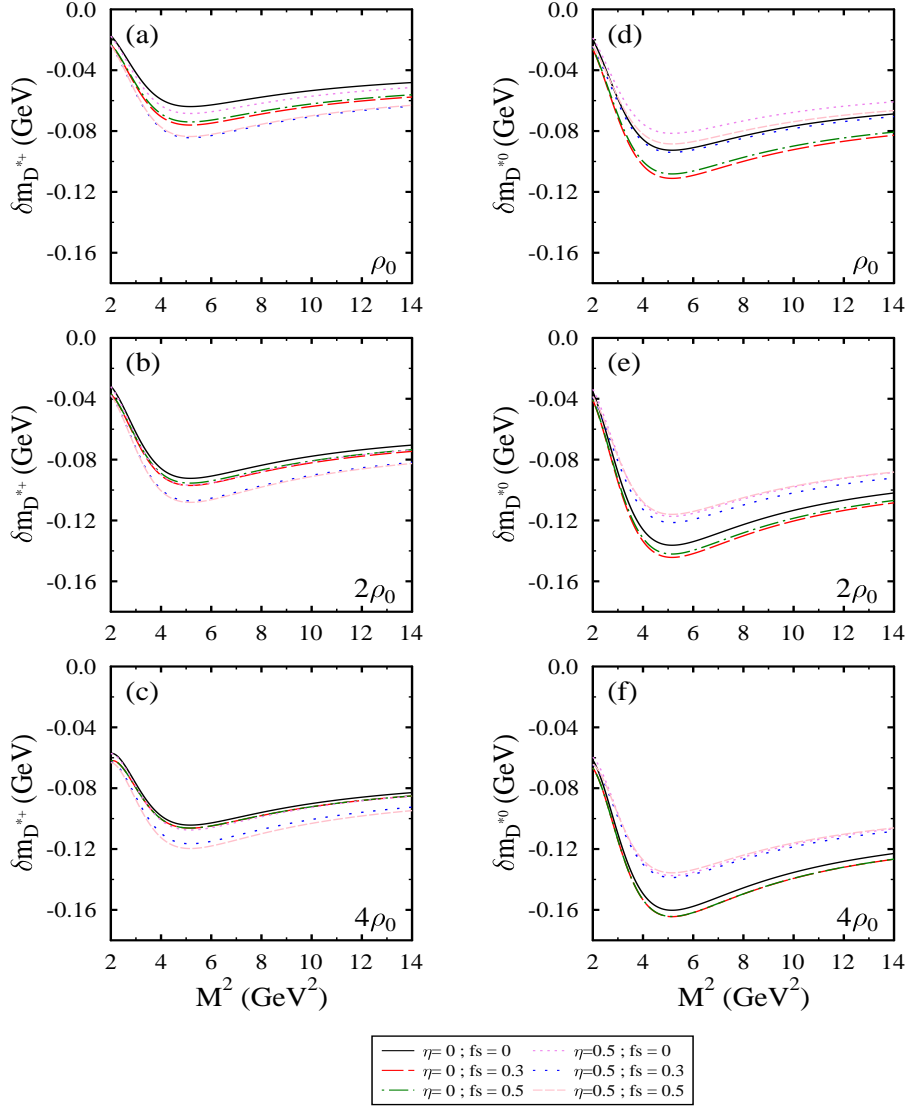
FIG. 4: (Color online) Figure shows the variation of mass shift of vector mesons D^{*+} and D^{*0} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

values of decay shifts are -39.7(-40.5), -47.2(-47.9) and -47.1(-47.8) MeV for the values of strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. For the same value of density but $\eta = 0.5$ above values modified to -39.9(-39.8), -47.5(-47.1) and -47.6(-46.9) MeV respectively. Above calculations show that the presence of hyperons along with nucleons in the medium
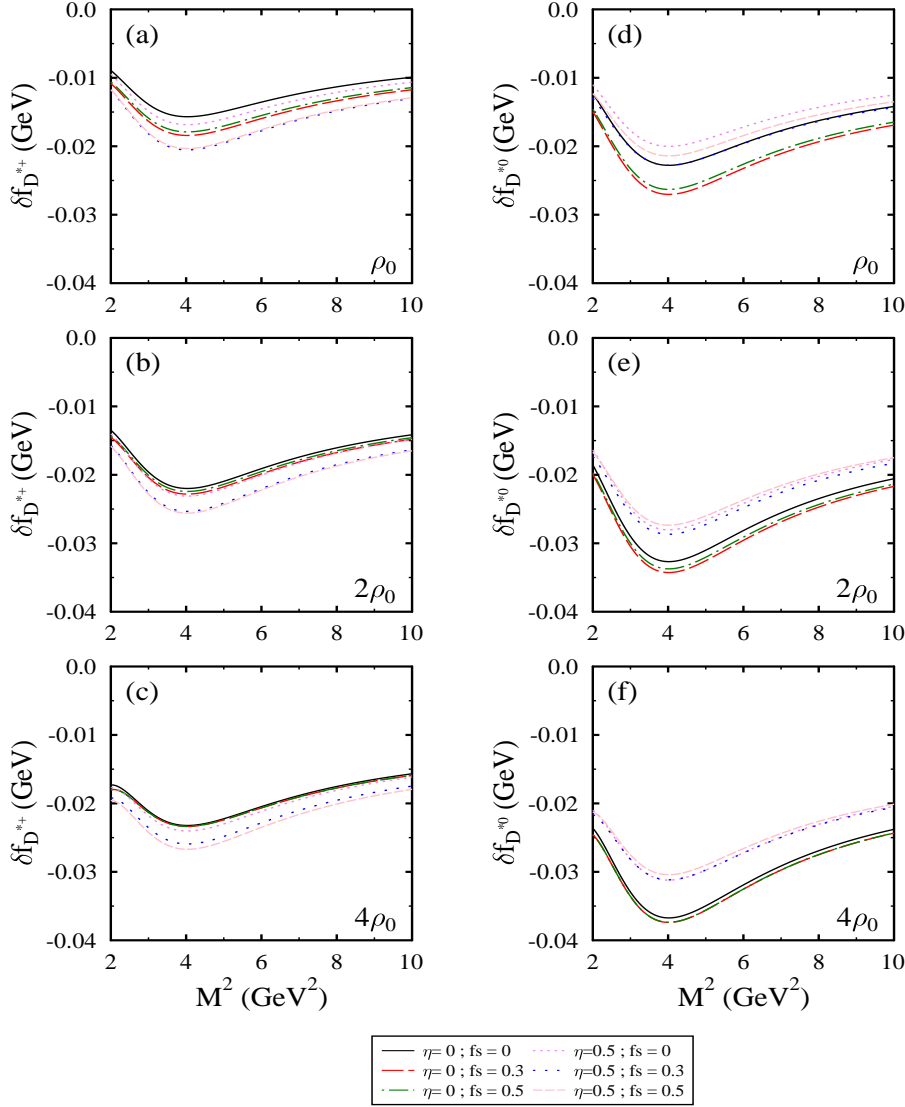
FIG. 5: (Color online) Figure shows the variation of shift in decay constant of vector mesons D^{*+} and D^{*0} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

causes more decrease in the values of decay constants of $D^\star$ mesons.

Figures (6) and (7) show the behaviour of mass shift and decay shift of B^{*+} and B^{*0} mesons as a function of squared Borel mass parameter for different conditions of the medium. In table (II) and (III) we tabulate the values of shift in masses and decay constants respec-
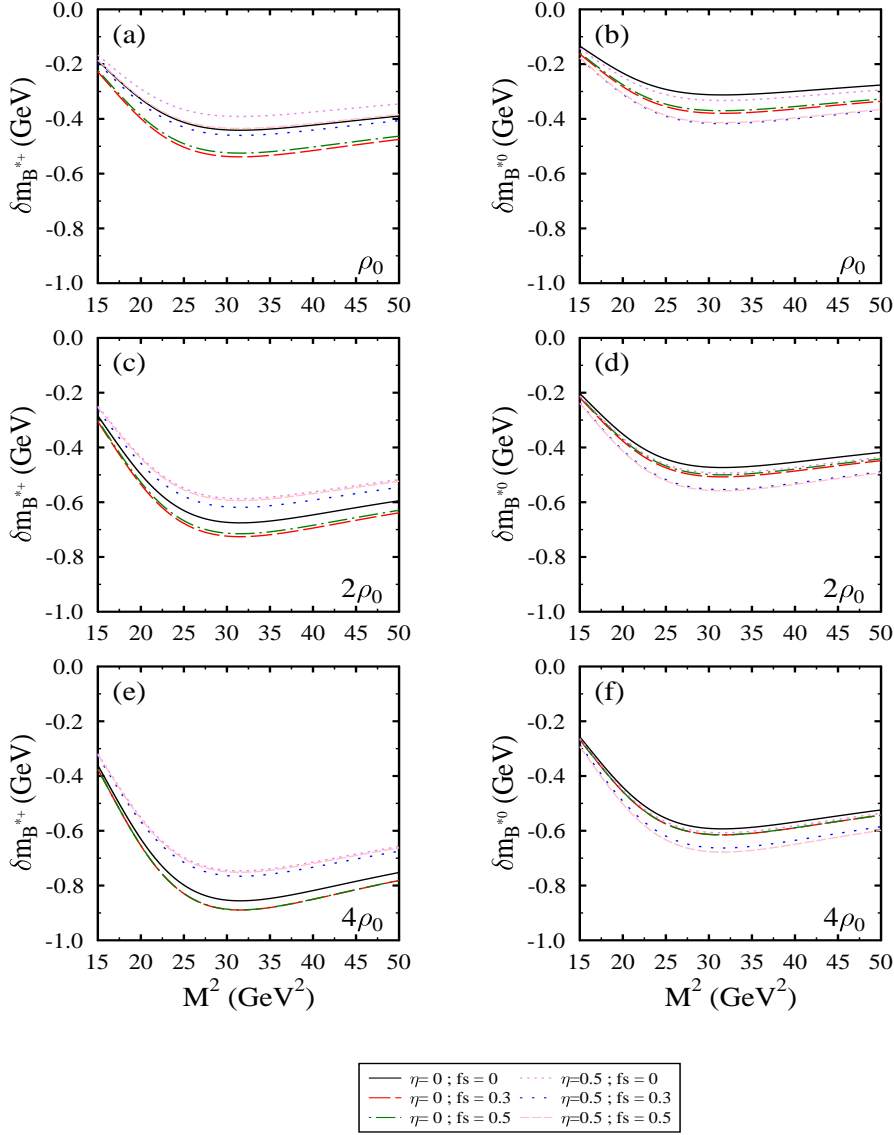
FIG. 6: (Color online) Figure shows the variation of mass shift of vector mesons B^{*+} and B^{*0} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

tively of B^{*+} and B^{*0} mesons in nuclear and strange hadronic medium. We observe that for the constant value of strangeness fraction, f_s, and isospin asymmetric parameter, η, the values of mass drop increases as a function of baryonic density. If we keep η and ρ_B constant then the drop in the masses of B^{*+} and B^{*0} mesons is observed to be more at
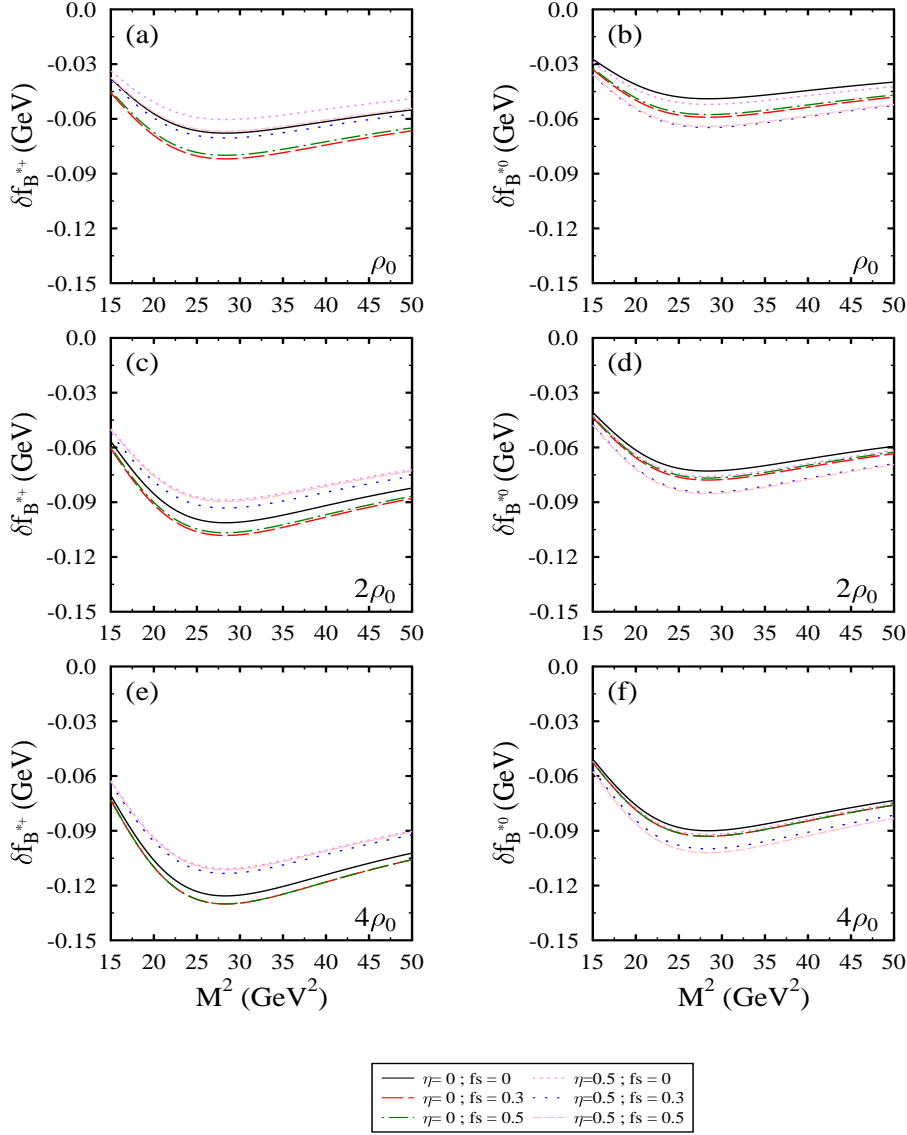
FIG. 7: (Color online) Figure shows the variation of shift in decay constant of vector mesons B^{*+} and B^{*0} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s =0$, 0.3 and 0.5.

higher strangeness fractions of the medium. This behavior of vector B^{*+} and B^{*0} mesons as function of density and strangeness fraction of the medium is consistent with that of vector D^{*+} and D^{*0} mesons. When we keep baryonic density and strangeness fraction, f_s constant then as compared to symmetric matter the drop in the mass of B^{*+} meson is less and that

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			B^{*0}	B^{*+}	B^{*0}	B^{*+}
		0	-312	-441	-332	-391
	ρ_0	0.3	-379	-539	-417	-460
		0.5	-370	-525	-413	-435
		0	-473	-675	-493	-587
δm_{B^*}	$2\rho_0$	0.3	-507	-726	-553	-618
		0.5	-499	-715	-558	-594
		0	-592	-855	-607	-746
	$4\rho_0$	0.3	-615	-889	-663	-766
		0.5	-614	-888	-677	-752

TABLE II: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in masses (in MeV) of B^{*0} and B^{*+} mesons for different values of strageness fraction f_s.

of B^{*0} meson is more in asymmetric matter. As can be observed from table (III), for the constant value of strangeness fraction f_s and isospin asymmetric parameter, η, the drop in the values of decay constant increases with the increase of baryonic density of hadronic medium. Also the drop in the decay constants of B^{*+} and B^{*0} mesons is observed to be more in strange medium as compared to nuclear medium. On the other hand when we keep baryonic density ρ_B and strangeness fraction f_s constant then decrease in the drop of decay shift of B^{*+} mesons but an increase in drop of decay shift of B^{*0} is observed with increasing isospin asymmetric parameter η.

In the present work we also studied the effect of strangeness fraction and isospin asymmetric parameter of hadronic medium on the mass shift and decay shift of strange charmed and bottom vector mesons D_s^* and B_s^* respectively. In figures (8) and (9) we present the variations of mass shift and shift in decay constant respectively of D_s^* and B_s^* mesons. The charmed strange and bottom strange mesons have one strange, s, quark and one heavy quark. The properties of these mesons are calculated in the medium through the presence of strange quark condensate, $\langle \bar{s}s \rangle$ in operator product expansion side of QCD sum rule equations (37) and (38). In symmetric medium i.e $\eta = 0$ and for baryon density, $\rho_B = \rho_0$, the values of mass shift of $D_s^*(B_s^*)$ mesons are observed to be -48.4(-204),-69.7(-295) and -77.6(-326)

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			B^{*0}	B^{*+}	B^{*0}	B^{*+}
		0	-48.9	-67.8	-52.0	-60.3
	ρ_0	0.3	-59.0	-81.9	-64.7	-70.4
		0.5	-57.6	-79.9	-64.1	-66.7
		0	-72.9	-101	-75.8	-88.7
δf_{B^*}	$2\rho_0$	0.3	-77.8	-108	-84.6	-93.1
		0.5	-76.7	-106	-85.3	-89.6
		0	-89.9	-125	-92	-110
	$4\rho_0$	0.3	-93	-130	-99.8	-113
		0.5	-92.9	-130	-102	-111

TABLE III: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in decay constants (in MeV) of B^{*0} and B^{*+} mesons for different values of strangeness fraction f_s.

MeV at strangeness fractions, $f_s = 0$, 0.3 and 0.5 respectively. For density, $\rho_B = 2\rho_0$, the above values are found to be -68.3(-299), -93.9(-408) and -109(-470) MeV respectively. From above discussion we observe that the strange charmed and bottom vector meson undergo mass drop in the hadronic medium. Also the values of mass drop is observed to be more in strange hadronic medium as compared to non-strange medium. In asymmetric parameter, $\eta = 0.5$ and for density, $\rho_B = \rho_0$, the values of mass shift of $D_s^*(B_s^*)$ mesons are observed to be -47.4(-200), -73.3(-309) and -83.5(-350) MeV for the strangeness fractions $f_s = 0$, 0.3 and 0.5 respectively. As we move to more dense medium i.e. $\rho_B = 2\rho_0$ then above shift in masses are observed to be -65.7(-289), -100(-433) and -119(-511) MeV for strangeness fraction f_s = 0,0.3 and 0.5 respectively. Thus we notice that the effect of increasing the density or strangeness fraction or isospin asymmetry of the medium is to decrease the masses of D_s^* and B_s^* mesons.

In figure (9) we have shown the effect of strangeness fraction and isospin asymmetric parameter on the decay constant of $D_s^*(B_s^*)$ mesons. In symmetric medium, at nuclear saturation density, $\rho_B = \rho_0$, the values of shift in decay constants of $D_s^*(B_s^*)$ mesons are found to be -12.5(-29.7), -17.9(-42.4) and -19.9(-46.8) MeV at strangeness fractions $f_s = 0$, 0.3 and
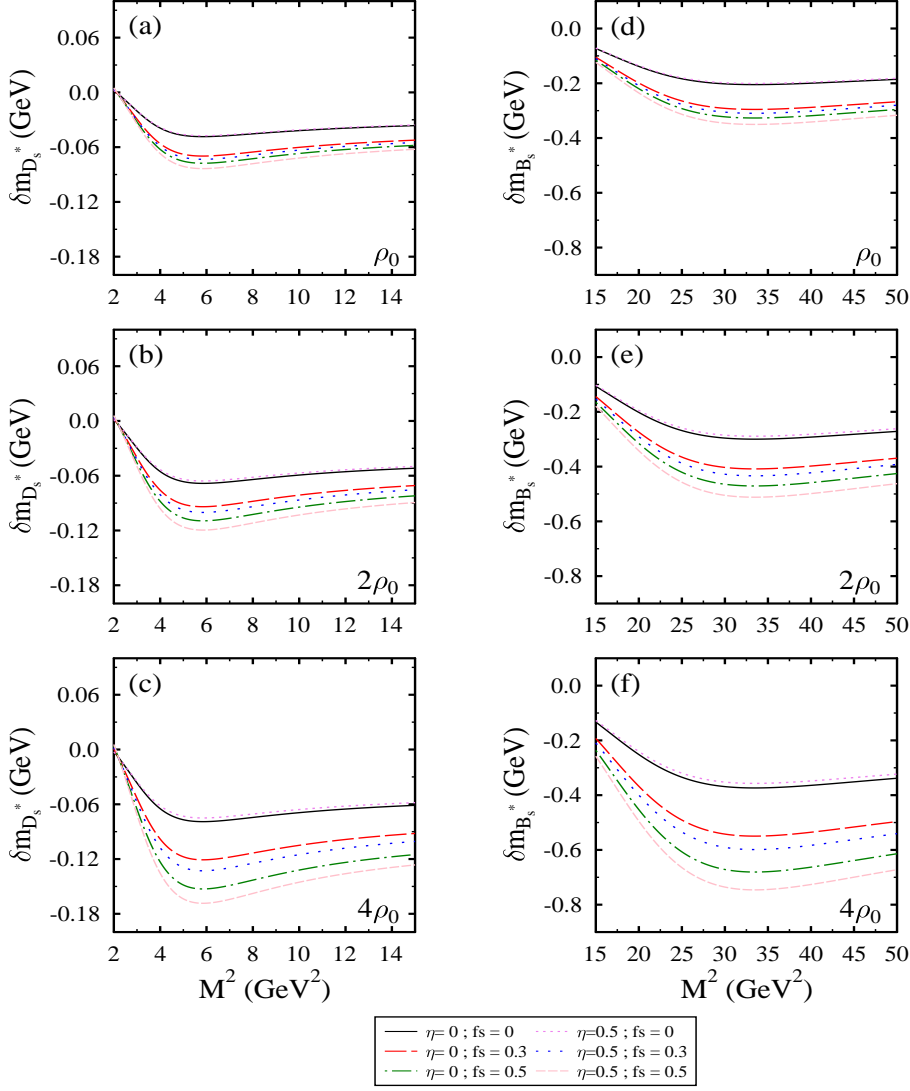
FIG. 8: (Color online) Figure shows the variation of mass shift of strange vector mesons D_s^* and B_s^* as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

0.5 respectively. This indicate that with increase in the strangeness fraction the values of decay constants decrease more from its vacuum value. It is also noticed that with increase in the baryonic density magnitude of shift in decay constant increases more e.g. at $\rho_B = 2\rho_0$ the above values altered to -17.3(-43.0), -23.8(-58.0) and -27.7(-66.5) MeV. In nuclear
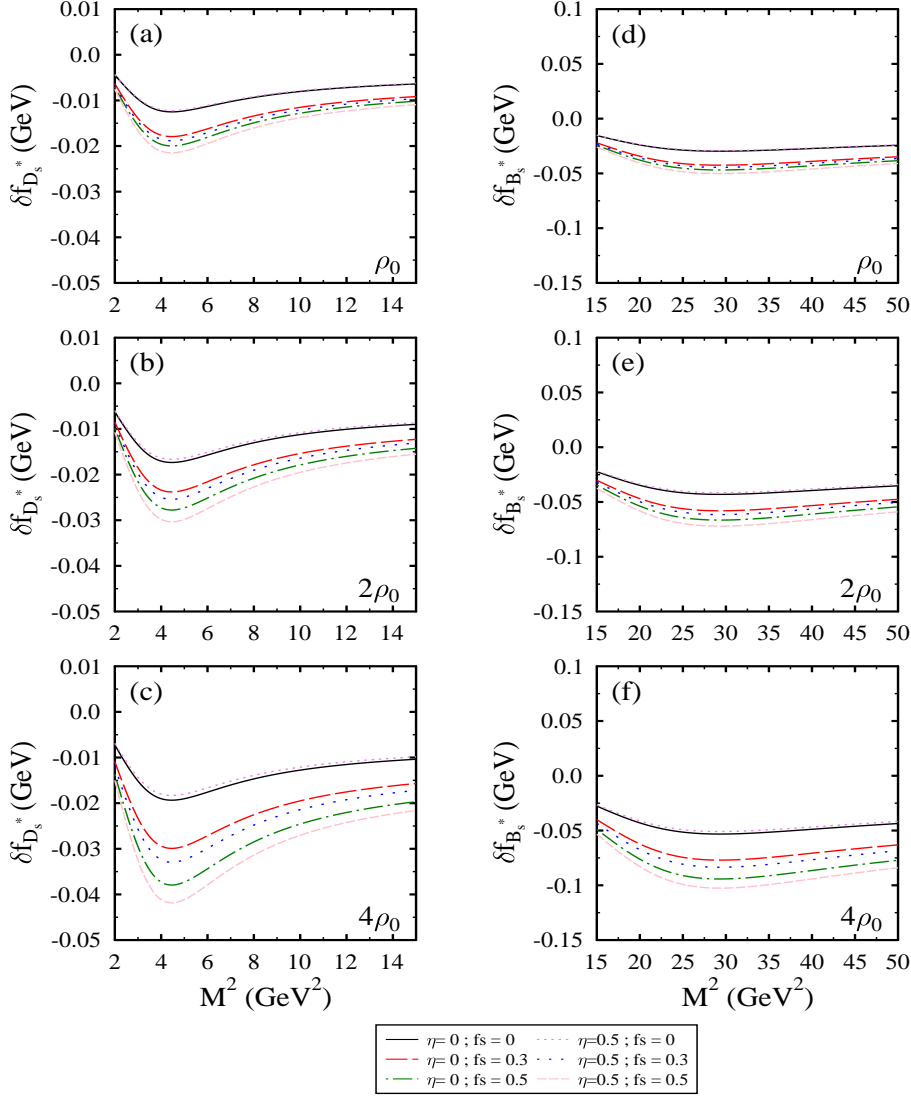
FIG. 9: (Color online) Figure shows the variation of shift in decay constant of strange vector mesons D_s^* and B_s^* as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s =0$, 0.3 and 0.5.

medium when we move from symmetric medium ($\eta=0$) to asymmetric medium($\eta=0.5$) we observed slight decrease in the magnitudes of decay shift of D_s^* (B_s^*) mesons. However, in strange hadronic medium ($f_s=0.5$) when we move from symmetric to asymmetric medium, increase in the magnitudes of decay shift is observed. For example, at nuclear saturation

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δm_{D_1}	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			D_1^0	D_1^+	D_1^0	D_1^+
		0	88	62	78	69
	ρ_0	0.3	106	74	91	82
		0.5	103	72	85	81
		0	130	91	114	95
	$2\rho_0$	0.3	139	97	119	106
		0.5	136	96	114	106
		0	158	110	139	112
	$4\rho_0$	0.3	163	113	142	122
		0.5	163	113	139	124

TABLE IV: Table shows values of mass shift (in MeV) of D_1^0 and D_1^+ axial vector mesons at different values of baryonic density and for different values of isospin asymmetry, η, and strangeness fraction, f_s, of hadronic medium.

density, $\rho_B = \rho_0$ the values of shift in decay constant of D_s^* (B_s^*) mesons are found to be -12.2(-29.1), -18.8(-44.4) and -21.5(-50.1) MeV at strangeness fractions, $f_s = 0$, 0.3 and 0.5 respectively.

It may be noted that among the various condensates present in the QCD sum rule equations (37) and (38), the scalar quark condensates, $\langle \bar{q}q \rangle$ have largest contribution for the medium modification of D and B meson properties. For example, if all the condensates are set to zero except $< \bar{q}q >$ then shift in mass (decay constant) for D^{*+} meson in symmetric nuclear medium ($fs = 0$ and $\eta = 0$) is observed to be -69(-17.8) MeV for $\rho_B = \rho_0$ and can be compared to the values -63.2 (-20) MeV evaluated in the presence of all condensates. Also the condensate $< q^\dagger \iota D_0 q >$ is not evaluated within chiral SU(3) model. However its contribution to the properties of D and B mesons is very small. Neglecting $< q^\dagger \iota D_0 q >$ only, the values of mass shift and decay shift in symmetric medium, at $\rho_B = \rho_0$, are observed to be -62 and -15 MeV respectively.

Figures (10) and (12) show the modification of mass shift of axial vector D_1 (D_1^0 and D_1^+) and B_1 (B_1^0 and B_1^+) mesons respectively and figures (11) and (13) show the decay shift of these mesons as a function of squared Borel mass parameter i.e M^2 for different

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			D_1^0	D_1^+	D_1^0	D_1^+
δf_{D_1}	ρ_0	0	29	20	29	22
		0.3	35	24	30	27
		0.5	34	24	28	27
	$2\rho_0$	0	43	30	38	31
		0.3	46	32	40	35
		0.5	46	32	38	35
	$4\rho_0$	0	53	37	47	37
		0.3	55	36	48	40
		0.5	55	37	47	42

TABLE V: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in decay constants (in MeV) of D_1^0 and D_1^+ mesons for different values of strangeness fraction f_s

values of baryonic density ρ_B , strangeness fraction f_s and isospin asymmetric parameter i.e η. In tables (IV), (V), (VI), (VII) we have given some numerical data to discuss the modification of masses and decay constants of axial vector mesons. For a constant value of strangeness fraction, f_s, and isospin asymmetric parameter, η, as a function of baryonic density a positive shift in masses and decay constants of axial vector D_1 (D_1^0 and D_1^+)and B_1 (B_1^0 and B_1^+) mesons was observed. For given density and isospin asymmetry, the finite strangeness fraction of the medium also causes an increase in the masses and decay constants of above axial vector mesons. For the axial vector D_1 and B_1 meson doublet, as a function of isospin asymmetry of the medium the values of mass shift and decay shift of D_1^0 (B_1^0) meson decreases (increases) whereas that of D_1^+ (B_1^+) increases (decreases). As discussed earlier in case of vector mesons, the reason for opposite behavior of D and B mesons as a function of isospin asymmetry of medium is the presence of light u quark in D_1^0 and B_1^+ mesons whereas the mesons D_1^+ and B_1^0 have light d quark.

Figure (14) and (15) shows the effect of strangeness fraction, isospin asymmetric parameter and baryonic density on the mass shift and decay shift respectively of D_{1S} and B_{1S} mesons. In tables (VIII) and (IX) we tabulate some values of mass shift and decay shift for

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	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			B_1^0	B_1^+	B_1^0	B_1^+
δm_{B_1}	ρ_0	0	216	300	229	268
		0.3	261	362	285	313
		0.5	255	353	282	297
	$2\rho_0$	0	322	445	334	393
		0.3	344	476	372	413
		0.5	339	470	375	398
	$4\rho_0$	0	401	554	409	492
		0.3	415	574	443	505
		0.5	415	573	452	497

TABLE VI: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in masses(in MeV) of B_1^0 and B_1^+ mesons for different values of strangeness fraction f_s

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			B_1^0	B_1^+	B_1^0	B_1^+
δf_{B_1}	ρ_0	0	53	74	56	66
		0.3	64	90	70	77
		0.5	63	87	70	73
	$2\rho_0$	0	80	117	83	98
		0.3	85	119	93	103
		0.5	84	118	93	99
	$4\rho_0$	0	100	140	102	124
		0.3	104	145	111	127
		0.5	104	145	113	125

TABLE VII: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in decay constants (in MeV) of B_1^0 and B_1^+ mesons for different values of strangeness fraction f_s.
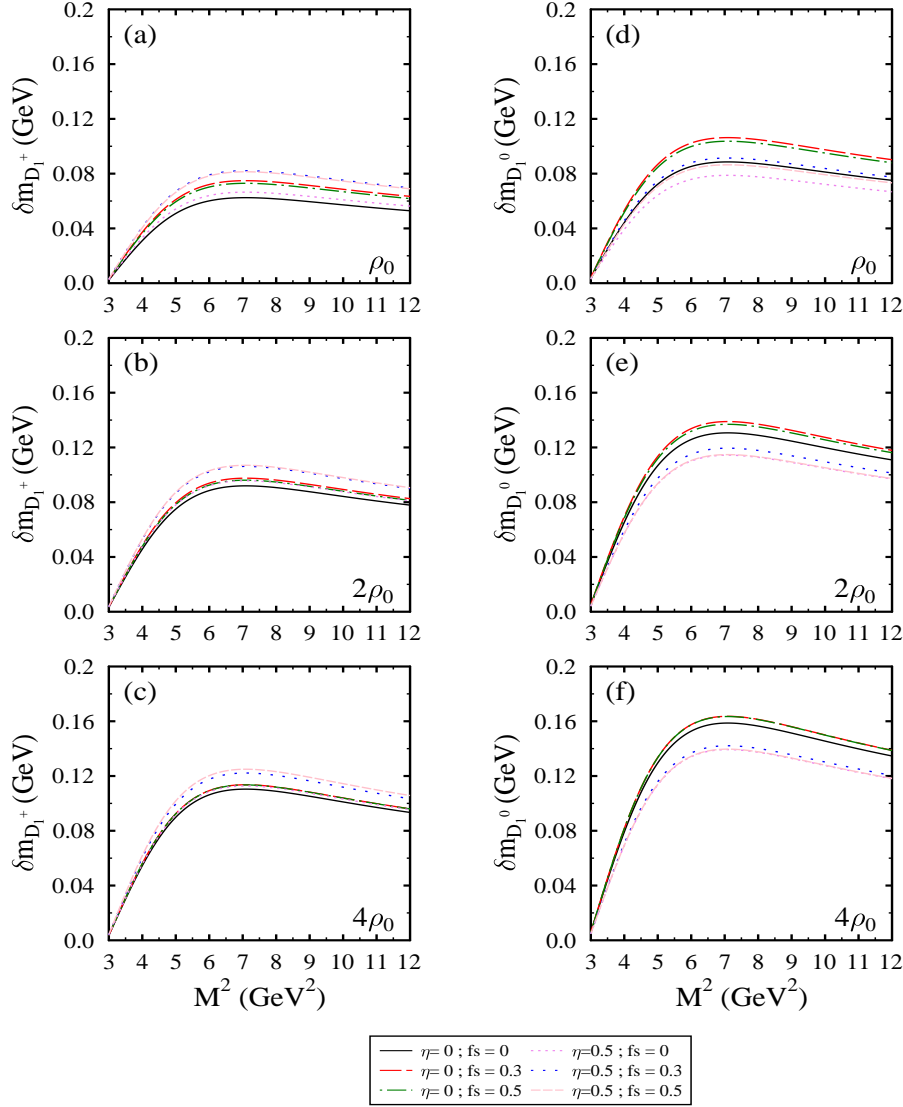
FIG. 10: (Color online) Figure shows the variation of mass shift of axial-vector mesons D_1^+ and D_1^0 as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

these strange axial vector D_{1S} and B_{1S} mesons. At finite baryonic density of the medium, an increase in strangeness fraction or isospin asymmetry of the medium causes an increase in the positive mass shift and decay shift of D_{1S} and B_{1S} mesons.

The mass shift and shift in decay constants of charmed and bottom vector and axial-

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			D_{1S}	B_{1S}	D_{1S}	B_{1S}
		0	44	164	43	161
	ρ_0	0.3	63	233	65	244
		0.5	69	257	74	274
		0	65	238	62	230
$\delta m_{D_{1s}}$	$2\rho_0$	0.3	86	319	91	337
		0.5	97	363	107	391
		0	81	297	78	285
	$4\rho_0$	0.3	115	422	124	456
		0.5	140	510	151	553

TABLE VIII: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in masses (in MeV) of B_{1S} and D_{1S} mesons for different values of strangeness fraction f_s.

	ρ_B	fs	$\eta=0$		$\eta=0.5$	
			D_{1S}	B_{1S}	D_{1S}	B_{1S}
		0	14	42	13	41
	ρ_0	0.3	20	60	20	63
		0.5	22	67	23	71
		0	20	62	20	60
$\delta f_{D_{1s}}$	$2\rho_0$	0.3	27	83	29	88
		0.5	31	95	34	103
		0	26	78	25	74
	$4\rho_0$	0.3	37	111	40	121
		0.5	45	136	48	148

TABLE IX: Table shows the effect of baryonic density ρ_B and isospin asymmetric parameter η on the shift in decay constants (in MeV) of D_{1S} and B_{1S} mesons for different values of strangeness fraction f_s
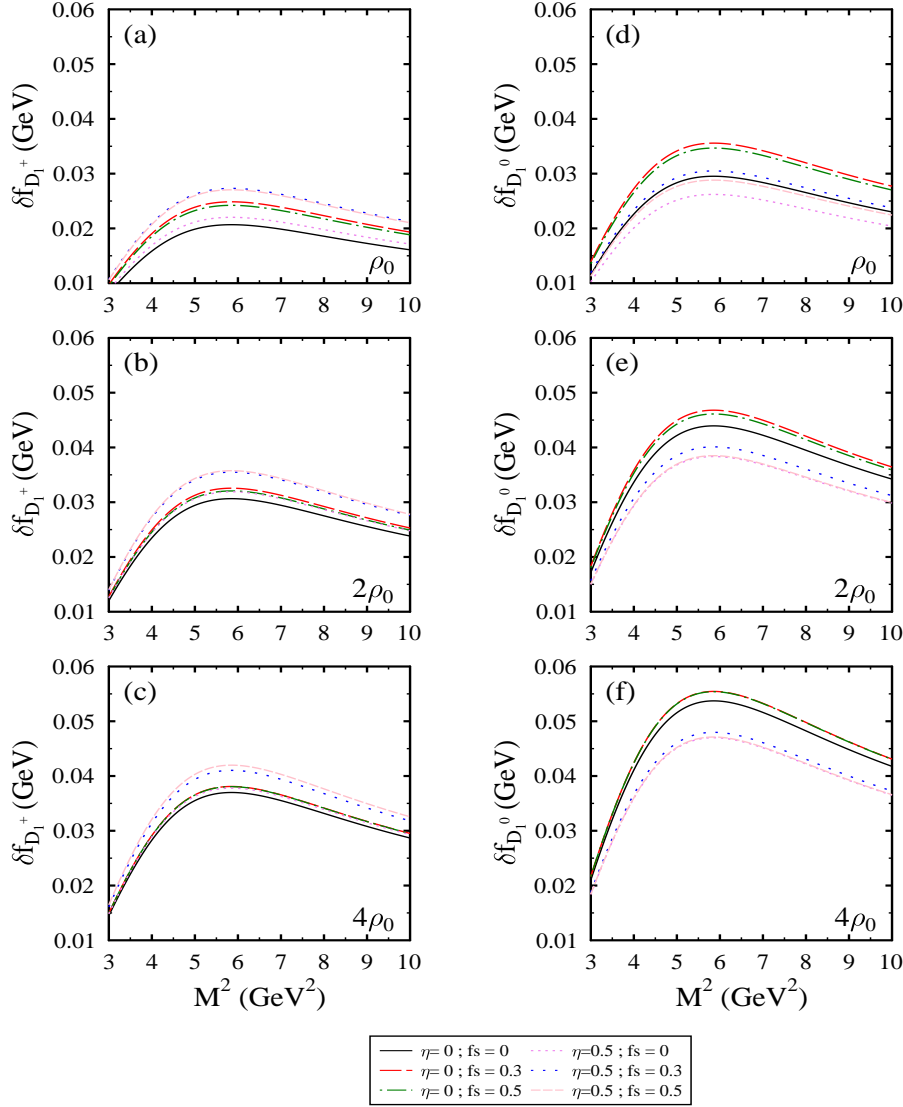
FIG. 11: (Color online) Figure shows the variation of shift in decay constant of axial-vector mesons D_1^+ and D_1^0 as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

vector mesons have been investigated in past using QCD sum rules in symmetric nuclear matter only [11, 29] . The values of mass shift for vector mesons D^* and B^* in leading order (next to leading order) calculations were -70 (-102) and -340 (-687) MeV respectively. For the axial vector D_1 and B_1 mesons the above values of mass shift changes to 66 (97) and
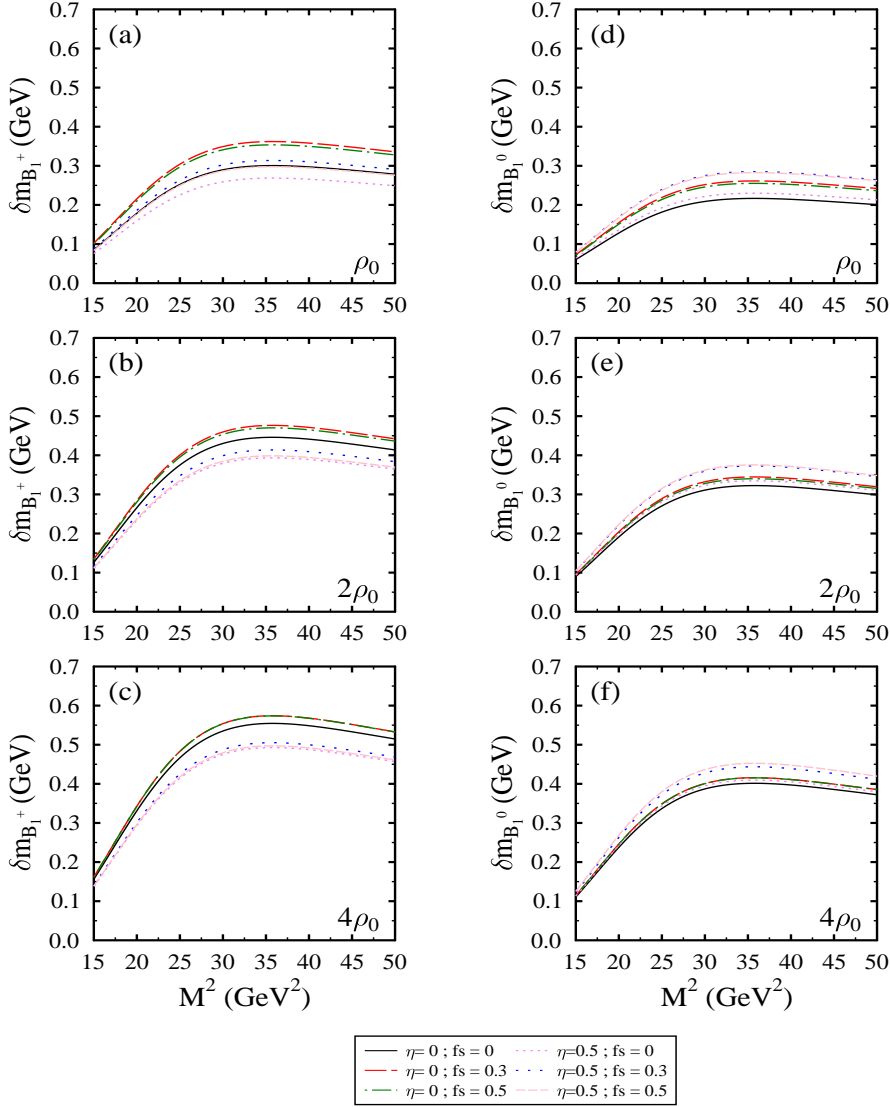
FIG. 12: (Color online) Figure shows the variation of mass shift of axial-vector mesons B_1^+ and B_1^0 as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

260 (522) MeV respectively. The values of shift in decay constant for D^* and B^* mesons in leading order (next to leading order) are found to be -18(-26) and -55(-111) MeV, whereas, for D_1 and B_1 mesons these values changes to 21(31) and 67 (134) MeV respectively. We can compare the above values of mass shift (decay shift) to our results -63 (-20), -312 (-48.9),
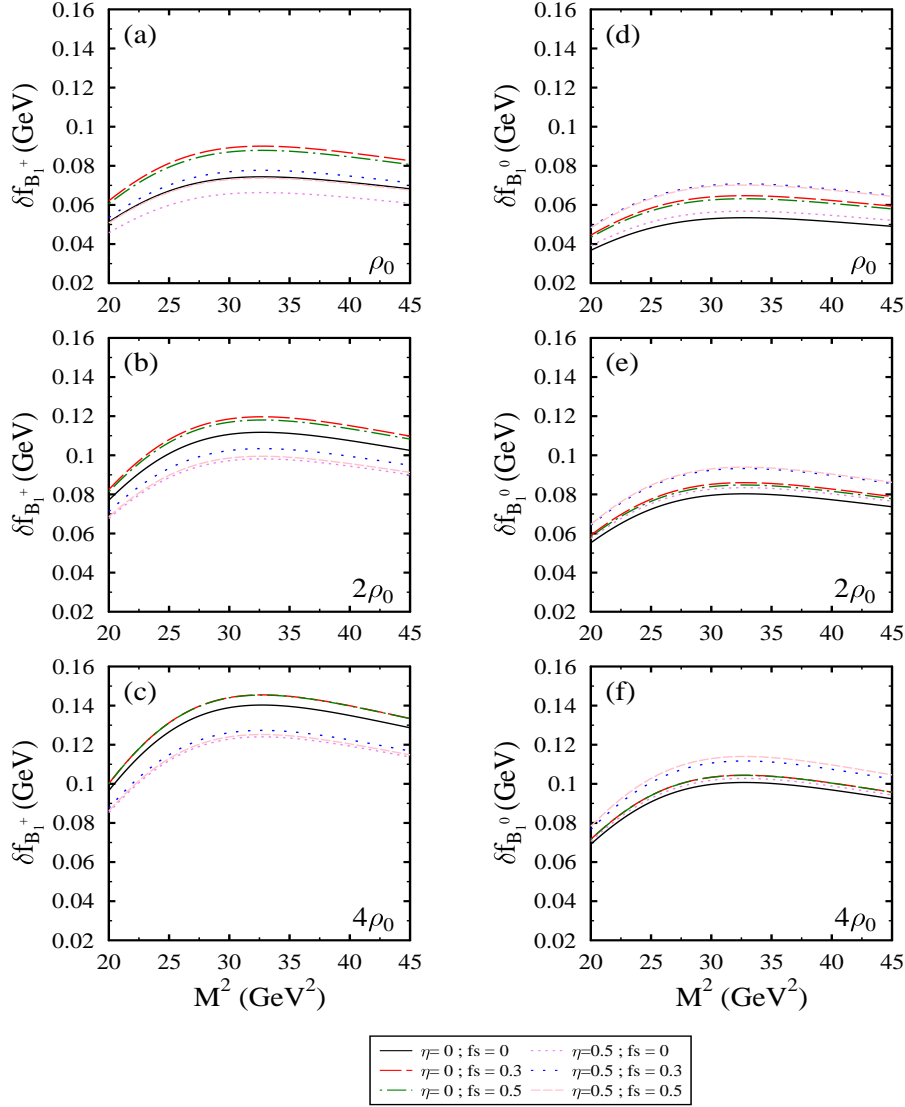
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FIG. 13: (Color online) Figure shows the variation of shift in decay constant of axial-vector mesons B_1^+ and B_1^0 as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s =$0, 0.3 and 0.5.

62 (20) and 216 (53) MeV for D^*, B^*, D_1 and B_1 mesons evaluated using $m_u = m_d = 7$ MeV in symmetric nuclear matter ($\eta = 0$ and $f_s = 0$). The observed negative values of mass shift for vector D^* and B^* mesons in nuclear and strange hadronic matter favor the decay of higher charmonium and bottomonium states to $D^*\bar{D}^*$ and $B^*\bar{B}^*$ pairs and hence
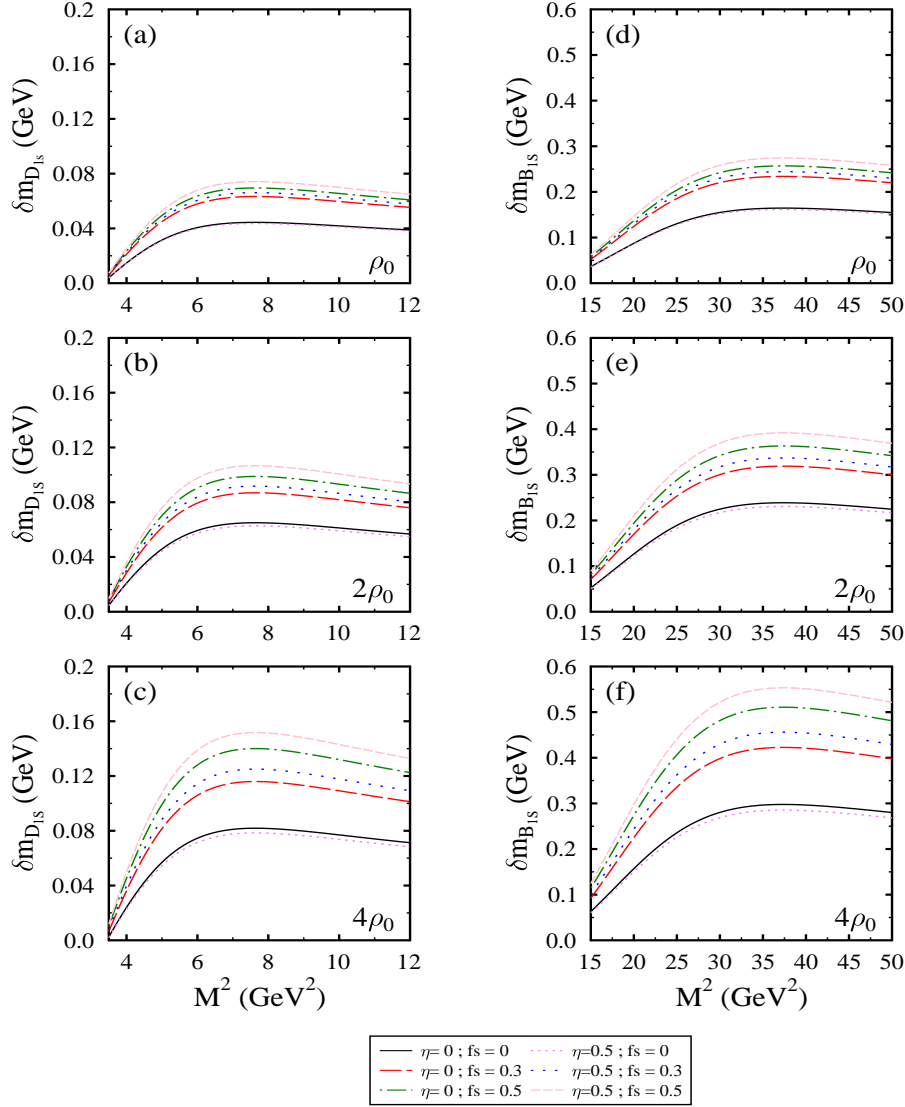
37

FIG. 14: (Color online) Figure shows the variation of mass shift of strange axial-vector mesons D_{1s} and B_{1s} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

may cause the quarkonium suppression. However the axial-vector meson undergo a positive mass shift in nuclear and strange hadronic medium and hence the possibility of decay of excited charmonium and bottomnium states to $D_1\bar{D}_1$ and $B_1\bar{B}_1$ pairs is suppressed. The observed effects of isospin asymmetry of the medium on the mass modifications of D and
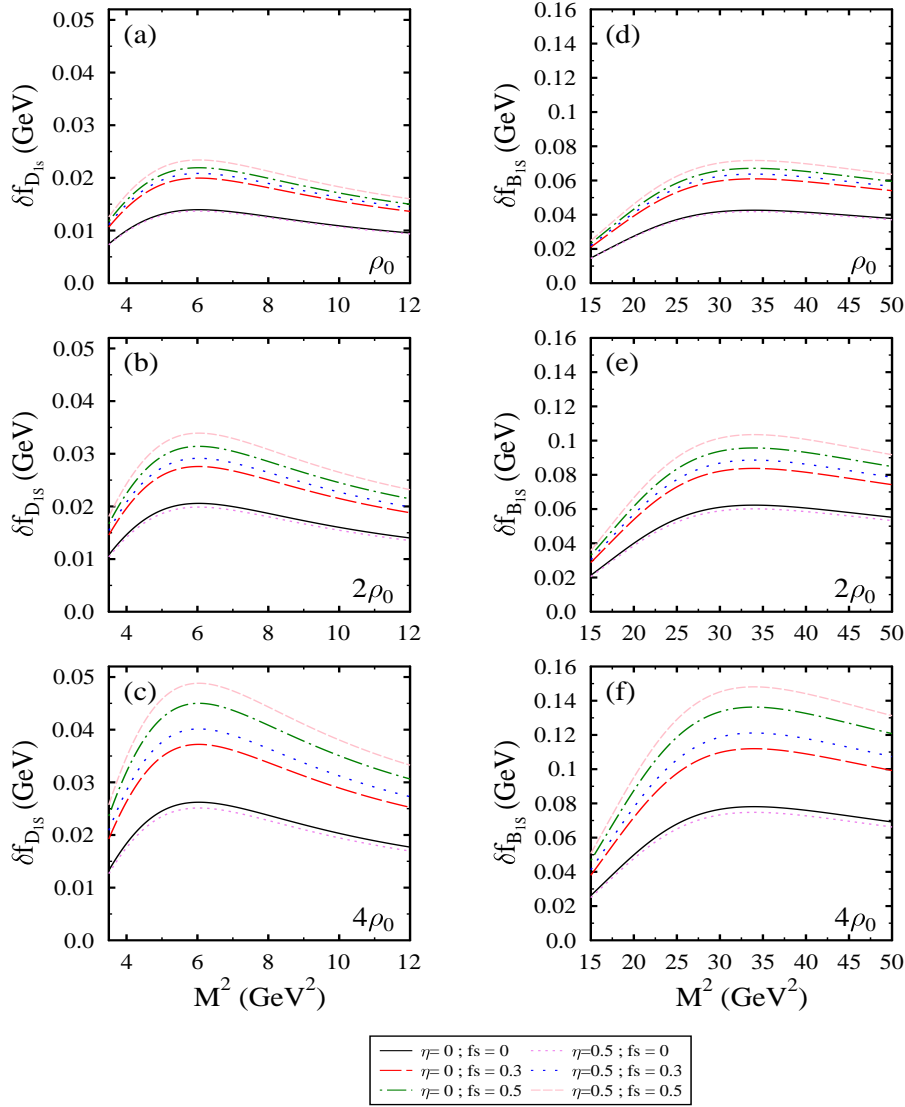
FIG. 15: (Color online) Figure shows the variation of shift in decay constant of strange axial-vector mesons D_{1s} and B_{1s} as a function of squared Borel mass parameter, M^2. We compare the results at isospin asymmetric parameters $\eta = 0$ and 0.5. For each value of isospin asymmetry parameter, η, the results are shown for strangeness fractions $f_s = 0$, 0.3 and 0.5.

B mesons can be verified experimentally through the ratios $\frac{D^{*+}}{D^{*0}}$, $\frac{B^{*+}}{B^{*0}}$, $\frac{D_1^+}{D_1^0}$ and $\frac{B_1^+}{B_1^0}$ whereas the effects of strangeness of the matter can be seen through the ratios $\frac{D^*}{D_S^*}$, $\frac{B^*}{B_S^*}$, $\frac{D_1}{D_{1S}}$ and $\frac{B_1}{B_{1S}}$. The traces of observed medium modifications of masses and decay constants can be seen experimentally in the strong decay width and leptonic decay width of heavy mesons [30].

For example, in ref. [21] the couplings $g_{D^\star D\pi}$ and $g_{B^\star B\pi}$ were studied using the QCD sum rules and strong decay width of charged vector $D^{\star+}$ mesons for the strong decay, $D^{*+} \longrightarrow D^0 \pi^+$ were evaluated using the formula,

$$\Gamma(D^* \longrightarrow D\pi) = \frac{g_{D^*D\pi}^2}{24\pi m_{D^*}^2}|k_\pi|^3, \tag{43}$$

where pion momentum, k_π is,

$$k_\pi = \sqrt{\frac{(m_{D^*}^2 - m_D^2 + m_\pi^2)^2}{(2m_{D^*})^2} - m_\pi^2}. \tag{44}$$

In equation (43) coupling $g_{D^*D\pi}^2 = 12.5 \pm 1$, $m_{D^\star}$ and m_D denote the masses of vector and pseudoscalar meson respectively. From equation (43) we observe that the values of decay width depend upon the masses of vector mesons, $D^\star$ and pseudoscalar D mesons. Using vacuum values for the masses of D mesons the values of decay width, $\Gamma(D^{*+} \longrightarrow D^0\pi^+)$ are observed to be 32 ± 5 keV [21]. However, as we discussed in our present work the charmed mesons get modified in the hadronic medium and this must lead to the medium modification of decay width of these mesons. For example, if we consider the in-medium masses of vector mesons from our present work and for pseudoscalar mesons we use the in-medium masses from ref. [16] (in this reference the mass modifications of pseudoscalar D mesons were calculated using the chiral SU(4) model in nuclear and strange hadronic medium), then in nuclear medium ($f_s = 0$), at baryon density, $\rho_B = \rho_0$, the values of decay width, $\Gamma(D^{*+} \longrightarrow D^0\pi^+)$, are observed to be 219 keV and 31 keV at asymmetry parameter $\eta = 0$ and 0.5 respectively. In strange medium($f_s = 0.5$), the above values of decay width will change to 84 and 25 keV at $\eta = 0$ and 0.5 respectively. We observe that the decay width of heavy mesons vary appreciably because of medium modification of heavy meson masses. In our future work we shall evaluate in detail the effects of medium modifications of masses and decay constants of heavy charmed and bottom mesons on the above mentioned experimental observables. Also the effects of finite temperature of the strange hadronic medium on the properties of vector and axial-vector mesons will be evaluated.

V. SUMMARY

In short, we computed the mass shift and shift of decay constants of vector and axial vector charm and bottom mesons in asymmetric hadronic matter, consisting of nucleon and

hyperons, using phenomenological chiral model and QCD sum rules. For this, first the quark and gluon condensates were calculated using chiral hadronic model and then using these values of condensates as input in QCD sum rules in-medium properties of vector and axial-vector mesons were evaluated. We observed a negative (positive) shift in the masses and decay constants of vector (axial vector) mesons. The magnitude of shift increases with increase in the density of baryonic density of matter. The properties of mesons are seen to be sensitive for the isospin asymmetry as well as strangeness fraction of the medium. The isospin asymmetry of the medium causes the mass-splitting between isospin doublets, whereas, the the presence of hyperons in addition to nucleons lead to an increase in the magnitude of shift in the masses and decay constants of heavy mesons. The observed effects on the masses and decay constants of heavy vector and axial vector mesons may be reflected experimentally in the production ratio of open charm mesons as well as in their decay width. The negative mass shift of charmed vector mesons as observed in present calculations may cause the formation of bound states with the nuclei as well as the decay of excited charmonium states to $D^*\bar{D}^*$ pairs causing charmonium suppression. The present work on the in-medium mesons properties may be helpful in understanding the experimental observables of CBM and PANDA experiments of FAIR project at GSI Germany.

Acknowledgments

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